EDINBURGH CENTRE FOR
ROBOTICS
Innovation Ready

Annual Review 2016/2017

HERIOT WATT UNIVERSITY

THE UNIVERSITY of EDINBURGH

EPSRC
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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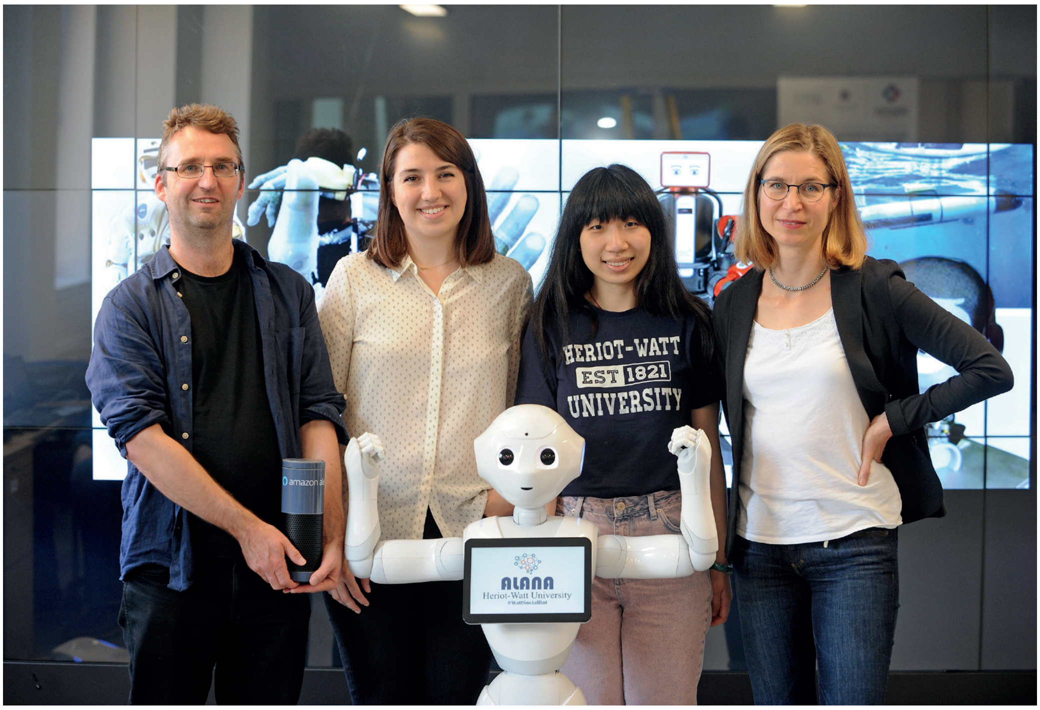

Members of the Heriot-Watt University Alexa challenge team
©The Herald newspaper

Secretary of State Damian Green visits Edinburgh Centre for Robotics at University of Edinburgh on announcement of the City Deal
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Foreword

Welcome to our 2016/17 Annual Review. Our third year of operation as an EPSRC Centre for Doctoral Training in Robotics and Autonomous Systems has been exceptionally busy, with a number of key events and developments further boosting our profile as one of the leading centres for RAS research in the UK.

At the start of the fourth year of our programme, we are pleased to report that we have 50 full-time PhD students engaged in the 4-year PhD. A similar number of affiliated students are pursuing related PhD or MSc programmes. Ten of our industrial supporters are providing full financial support to studentships, augmenting those of EPSRC.

Our Equipment Facility at Heriot-Watt University is now operational and we are making full use of this new space which includes a Human Robot Interaction Lab and a double height Field Robotics Lab, allowing for the operation of drones. Our Living Space Lab in the Lyell Building has been transformed into a home complete with kitchen and bathroom where important research into social care robots will be carried out. Work on the £45M Bayes Centre at the University of Edinburgh is progressing rapidly with an expected completion date of early 2018.

Dr Sen Wang and Dr Ioannis Konstas have recently joined the academic team; appointments which further strengthen our expertise in localisation, navigation and robotic vision, and natural language processing and generation. Congratulations are due to Centre academics Helen Hastie and Verena Rieser on their respective appointments to Professor in the School of Mathematical and Computer Sciences at Heriot-Watt University.

Contributions by Centre staff and students to the life of Heriot-Watt University were recognised in the 2017 Spirit of Heriot-Watt Awards with the ERF2017 committee and the Year of Robotics organising team receiving awards in the Outward Looking and Best Team categories. Two teams of students, one from each University, were among the twelve teams chosen and sponsored by Amazon to compete in the Alexa Challenge; the team from Heriot-Watt University has gone through to the final. University of Edinburgh led students from the Centre won first prize for Greatest Potential for Positive Impact in the Robots for Resilient Infrastructure Competition, an International Robotics Challenge Event held during UK Robotics week.

Keynote speakers have included Professor Chris Atkeson (CMU) and Michael Talbot (Centre for Connected and Autonomous Vehicles) who both presented at our second annual conference. Professor Atkeson entertained the audience with his talk 'What next for humanoid robotics?' Michael Talbot gave an informative talk on 'The Pathway to Driverless Cars: Connected and Autonomous Vehicles in the UK'. We were honoured to host Dr Robert Ambrose from NASA who delivered a Distinguished Lecture titled "Robotic Caretakers: Enabling the Pre-Deployment Approach to Human Space Exploration" at the School of Informatics at the University of Edinburgh. Professor Jérôme Szewczyk from Pierre and Marie Curie University presented on "Current Trends and Technical Challenges in Surgical Robotics". This was followed by a half-day workshop, in conjunction with Dr Suphi Erden, where collaboration opportunities in the domain of laparoscopy, laparoscopy skill training and robotic assistance for laparoscopy were considered. A high-profile delegation from China, including Mr Hu Chunhua, Party Secretary of CPC Guangdong Committee, and Mr. Wen Guohui, Mayor of Guangzhou City, visited the Centre facilities at University of Edinburgh and were shown demonstrations of Valkyrie, the Husky UGV and PR2 Humanoid. Visits have been undertaken by Centre Academics to Brazil, China and Japan to promote the research activities of the Centre and to discuss collaboration opportunities.

2017 was designated "Year of Robotics" at Heriot-Watt University with a year-long series of events which celebrate and share the University's contributions to the development of robotics and AI. The Year of Robotics started on a high note when the Centre hosted 800 delegates at the European Robotics Forum in March. Other key Year of Robotics activities included participation in the Edinburgh International Science Festival, The Pint of Science Festival which brings eminent scientists to local pubs to share their latest research and findings, and demonstrations at CarFest North and South. Pepper, one of our humanoid Robots appeared on Blue Peter to answer questions from the audience who were interested to know if Pepper believes in unicorns.

The year also ended on high note with the welcome announcement of the £1.1 billion Edinburgh City Deal. A significant portion of this investment will be used to fund a new centre for research into robotics, to be known as the National ROBOTARIUM, at Heriot-Watt and Edinburgh Universities.

We regularly post news items to our website edinburgh-robotics.org and on social media. We also produce a regular newsletter to which you can subscribe to keep up to date with our latest news and developments.

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Breaking news.... The Centre's ORCA Hub bid, to establish a world leading centre in Robot Assisted Offshore Asset Integrity has been successful. This brings a combined £35M of new funding from EPSRC and Industry, commencing 2nd October 2017.

About us

EDINBURGH CENTRE FOR ROBOTICS
Innovation Ready

The Edinburgh Centre for Robotics (ECR) is a £35m joint venture between Heriot-Watt University and the University of Edinburgh, supported by EPSRC, Industry and the Universities.

It captures the expertise of 45 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 an EPSRC Centre for Doctoral Training (CDT) in Robotics and Autonomous Systems which trains innovation–ready postgraduates, and the ROBOTARIUM, a £8m national capital equipment facility.

The Centre includes affiliated students engaged in related EU, EPSRC and UK-MoD research programmes, the VIBOT Erasmus Mundus Masters programme and local EPSRC CDTs in Embedded Intelligence, Data Science, Applied Photonics and Pervasive Parallelism. This year we welcome students from 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 aim to apply 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 oil and gas, 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.

Centre Culture

Vision	•	To advance the UK's industrial potential in the robotics revolution through a new generation of highly skilled and innovation-ready researchers alongside cutting edge research that transitions to disruptive cross-sector applications
Values	• • • • • • •	Cutting edge research Robust training Equality & diversity Impact Creativity Entrepreneurship Outreach
Objectives	• • •	Supply urgent need for skilled, industry and market aware researchers in RAS Prepare students to enter, lead and create the UK's innovation pipeline in robotics sector Solve scientific challenges relating to interactions between robots, autonomous systems, their environments and people to realise productive and useful assistive or remote systems in homes, workplaces and industries

Internal Engagement

With a steadily increasing team of staff across two universities and a growing student body, it is important that the Centre engages internally to ensure all staff understand our strategy and how their work contributes to the overall performance of the Centre.

We use a number of different channels to promote internal engagement. Our Centre website has a News and Events section which is regularly updated. We have a robust social media strategy and regularly share information about student and academic activities via our Facebook, Twitter and LinkedIn accounts.

The Centre's Executive meets monthly with a representative from each student cohort attending. Executive meeting minutes are shared with the academic team, and student representatives feedback points of relevance to their respective cohorts.

We produce a bi-monthly newsletter which is shared internally but is also sent to external subscribers. This newsletter highlights staff and student achievements, and provides updates on new staff and other Centre developments. Special editions of the newsletter are produced for key events such as our participation in UK Robotics week.

All academic staff are encouraged to play an active role in the annual student recruitment process. Between the months of January and May, we hold regular consensus meetings to discuss student applications to which all staff are invited. We also ensure that a wide range of staff are involved in the interview process and final selection.

With each new student intake, staff are invited to pitch to be mentors. Academics are also invited to propose MSc projects for each new cohort of students.

In addition to our annual Centre conference which takes place each October, we have also introduced an Annual Review meeting to which all staff and students are invited. The focus of this meeting is to bring all staff and students together to discuss current activities of the Centre and new developments but importantly it also provides a forum for networking.

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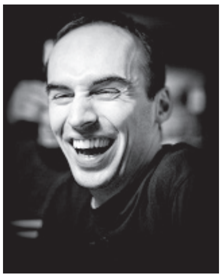

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EPSRC Centre for Doctoral Training

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.

"This past year has been unbelievable. The range of taught courses is amazing, I feel like I've learnt more in the last year than in any other. I also really enjoyed the freedom to define my own project, with the guidance of my supervisor. In addition to the teaching, there are so many amazing opportunities available to you which have made my time in the CDT really fascinating."

Siobhan - PhD Student, 2016 cohort

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 studentships covering tuition fees and maintenance at prevailing EPSRC rates.
- Access to our world class infrastructure, enhanced through our £8m ROBOTARIUM facility.
- Students benefit from supervision by academic experts from both institutions and graduate with a joint PhD from the University of Edinburgh and Heriot-Watt University.
- Excellent training opportunities, including masters level courses in year one, supplemented by training in commercial awareness, social challenges and innovation.
- Enterprise funds available to support development of early commercialisation prototypes.
- Opportunity for competitive selection for funding from Cambridge IGNITE and MIT Sloan School of Management Entrepreneurship Programmes.
- Opportunities to compete in international robot competitions (RoboCup, DRC, SAUC-E Autonomous Underwater Vehicle Challenge Europe).

"I particularly enjoyed the structure of the program, with a number of research-oriented courses, giving us the ability to identify the current state of a scientific field and plan for possible improvements. Having just finished the MSc part of the program, I feel fully prepared to start my PhD."
Martin - PhD student, 2016 cohort

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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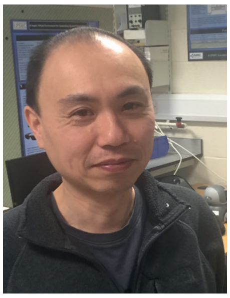

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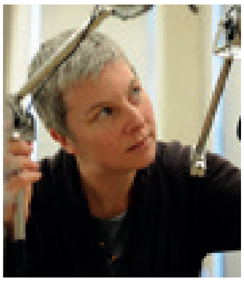

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Optimisation-based control and design of exoskeletons

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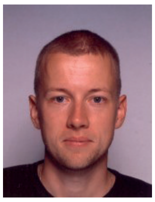
Hierarchical prediction and planning for Human-Robot Interaction



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Deep Learning of Human Activity in Audio and Video streams

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Machine learning methods for upper limb prosthesis control under the presence of EMG concept drift

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Manipulation of uncooperative objects in zero-gravity with modular self-reconfigurable robots

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Online Optimal Replanning in Complex Environments/Model Predictive Control for Humanoid Robots

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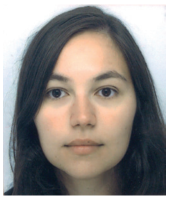
A Framework for Knowledge Acquisition and Grounding through Situated Interactive Dialogue and Visual Demonstrations



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Humanoid Visual Simultaneous Localisation and Mapping Fusing Proprioception

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High-Performance Computing for Robotic Systems using Low-Power Accelerators

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Architecture for Information-Aware Network of Sensors

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Physical Scene Understanding Through Active Manipulation

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Detection and Tracking of Subsea Pipelines from an AUV

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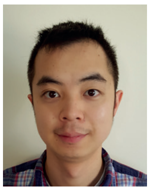
SMASH: One-Shot Model Architecture Search through HyperNets



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Muscle Activation Patterns for Skilled Arm Movements in Minimally Invasive Surgery

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Confidence in Autonomous Robotics Applications

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Adaptable robotic manipulation of fluids using fast but approximate fluid simulation

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Real-Time Vision-Based Gesture Learning for Human-Robot Interaction in Social Humanoid Robotics

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Application of force control to a robotic manipulator for cleaning a non-flat surface

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Articulated Tracking for Humanoid Manipulation Tasks

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Swarm robotics applied to search and rescue scenarios

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Robotic Assisted Drawing

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Exploring Paths Toward Embodied Cognition in Robots

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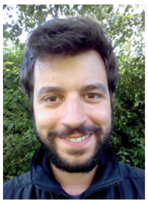
Soft robotic control through stacked simplicity



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Flocking behaviour in a swarm of off-the-shelf flying drones

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Human-Robot Collaboration and Robotic Dynamic Identification

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Autonomous navigation

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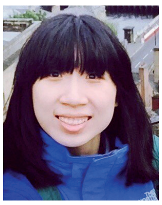
Intention Aware Human-Robot Collaborative Manipulation of Large Objects



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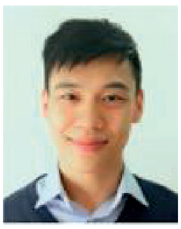

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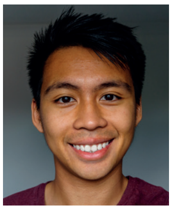

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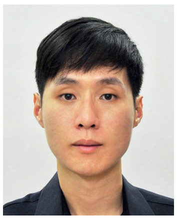

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Research Themes

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 modeling, 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.

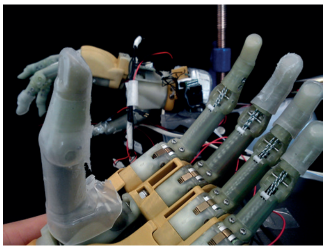
We study nature to develop **bio-inspired** systems that sense and process data using the methods that have evolved in biological organisms. Finally, we also think about **ethical issues**, the decisions robots should and shouldn't be allowed to make, and the **regulatory** environments they work in.

	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	

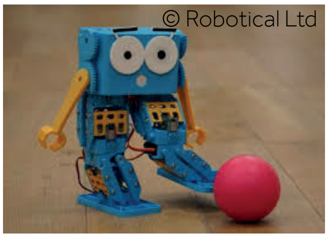
Centre Impact

In the same way the ICT revolution disrupted everything that uses data, the robotics revolution now underway is affecting everything that moves. As one of the Eight Great Technologies, robotics and autonomous systems is one of the priority investment areas across all areas of the UK Government, seeking significant cross sector synergies. In a nascent industrial strategy, it is one of the technology areas with real potential to generate economic growth.

The Edinburgh Centre for Robotics through some of its constituent laboratories has a track record in activities generating this growth. Our technologies and skills have created, seeded 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.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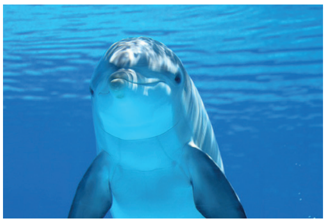
In addition to entering into discussions on RAS strategy at Cabinet Office level, Centre staff are also providing strategic advice to several large corporates and other sponsors in Offshore Energy and Security markets based on research from the Centre.

© Subsea 7

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 inspecting inside pipelines and tubular structures externally. Other new designs of prosthetic hands have benefitted from advanced control system design using machine learning.



From our work, affordable fully programmable, customisable walking robots for children, makers and educators are going to revolutionise how robotics and related STEM subjects are taught in schools and universities. New generations of companion and assistive robots are going to change the way we support an ageing and isolated population that is growing, with limited resources. Shared-autonomy developments will reduce costs and dependency on manpower in drilling as oil prices fluctuate and for order fulfilment in distribution warehouses and manufacturing.

Selected projects from across the Centre 2016/17

Research Area: Deep Learning, HRI

Improving child robot interaction by understanding gaze

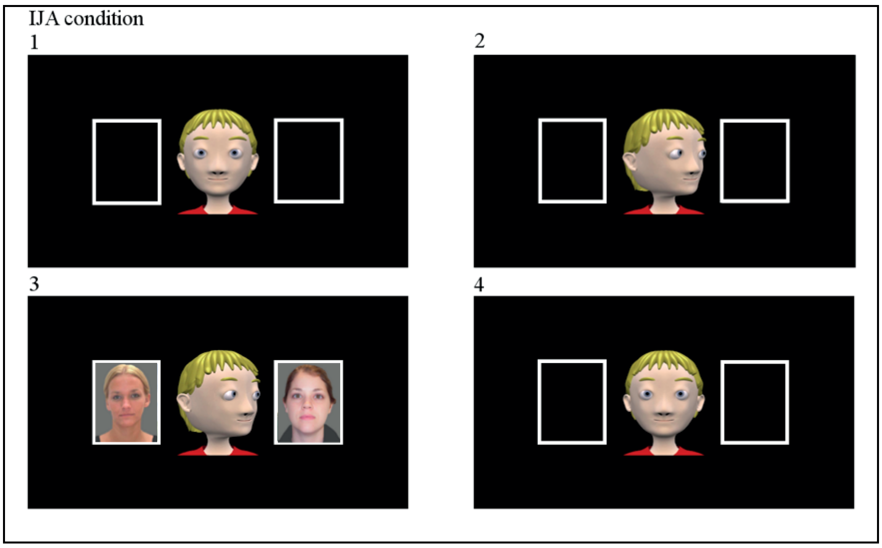
Supervisor: Dr Katrin Lohan
PhD candidate: Eli Sheppard

Objectives

This work aimed to utilise gaze data from both neurotypical children and those with Autism Spectrum Disorders (ASD) to improve understanding of the behaviours of both groups during a joint attention task with a virtual agent.
Typically, an assessment of gaze behaviour is used as part of the diagnosis process for ASD. As such, we aimed to determine if either gaze or pupil diameter data could be reliably used to distinguish the two groups using a deep neural network (DNN).

Approach

Children took part in a joint attention (JA) task where they had to initiate joint attention with a virtual avatar called Danny. The children were shown two images of people's faces. They had to select an image to look at and memorise that face, Danny would then turn to look at the face they had selected.
During this task, gaze and pupil diameter data was collected using a Tobii E-prime eye tracker device.
From this data we trained DNNs to distinguish the two groups from either their gaze locations during the task or from the changes in the (normalised) diameter of their pupil.
Further to this, we performed a k-means clustering on the pupil diameter data, to determine the different pupil behaviours exhibited by the two groups.



Results

The DNN was able to distinguish the two groups with 99.8 and 96.6 percent accuracy when trained on pupil diameter and gaze location data respectively. This shows a strong correlation between ASD and altered eye behaviour.

The k-means clustering showed that the ASD group had less varied behaviour displaying only 3 behaviours whilst the typically developing group showed 5 different behaviours. What is also noticeable about the ASD group is that they spend significantly more time looking at Danny.

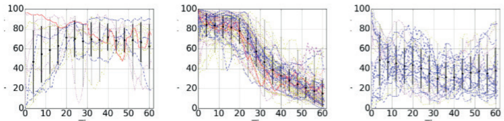


Fig. 4: ASD pupil diameter behaviour in clusters.

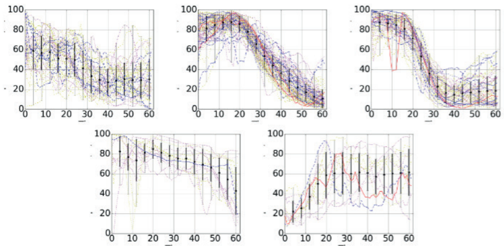


Fig. 5: TD pupil diameter behaviour in clusters.

Impact

We hope this work will allow for robots to be better prepared for interacting with both neurotypical children and those with ASD. Children with ASD benefit greatly from early intervention and in the future, robots could be used as educational aids as their predictable and repeatable behaviour can make it easier for those with ASD to interpret the intentions of the robot.

Further to this, there is potential for machine learning to be used as a tool for doctors when diagnosing these types of conditions.

Future Work

In the future, we will be using gaze data to allow robots to make decisions about their behaviour in order to produce a more engaging interaction in order to support children's learning. We aim to develop a system which can be used by a robot tutor to educate children whilst maintaining their engagement and attention regardless of any neurological differences.

Publications

K. S. Lohan, E. Sheppard, G.E. Little, G. Rajendran "Towards improved child robot interaction by understanding eye movements", IEEE TCDS 2017 Special Issue A sense of interaction in humans and robots: from visual perception to social cognition.

Research Area: Aerial Robotics

Active sensing of spatiotemporal phenomena with a UAV

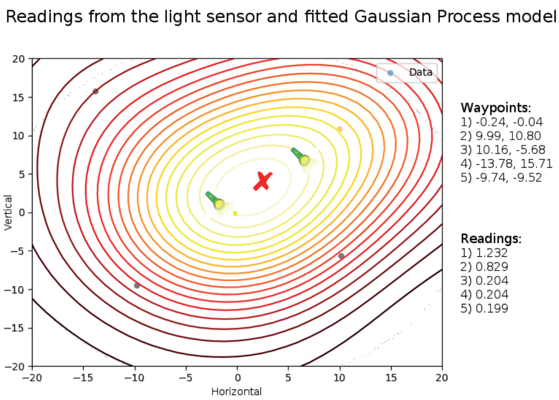
Supervisor: Dr Subramanian Ramamoorthy
PhD student(s): Martin Asenov

Objectives

This project is an investigation into the use of resource constrained UAV platforms for actively acquiring information from and creating models of three-dimensional spatiotemporal phenomena, such as chemical dispersing in the wind.
This project, initiated in collaboration with optical scientists who are devising novel broadband spectroscopic sensors (Prof. Derryck Reid and the Ultrafast Optics Group at Heriot-Watt University) and funded by the UK Centre for Defense Enterprise, is motivated by the long term goal of devising improved monitoring and detection systems in hazardous environments, such as those faced by emergency and forensic services. As a step towards this ambitious longer-term goal, we have developed a platform for studying active sensing with sensors capable of measuring temperature, wind speed, gas concentrations and light intensities (each representing a spatiotemporal process of interest in different applications).
The key focus of this research project is on building models from sparse and incomplete measurements – which is realistically all that the combination of platform resource constraints and the dynamic environments will permit; and using those models to guide path planning for actively steered information acquisition.

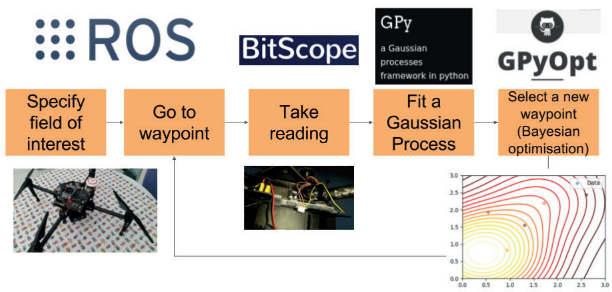
Approach

We have developed a platform based on the DJI Matrice 100 research grade UAV and onboard computation with an NVidia TX1 embedded computer. Custom mechanical design by our collaborators enabled the mounting of a Broadband Fourier Transform Spectrometer onto the M100 chassis, for on-board processing of gas concentration measurements. Other sensors, such as for light intensity or temperature, were of course much simpler to mount.
The acquired information is used to fit a Gaussian Process model, which in the initial stages of the experiment have involved just spatial variation (with temporal variability being restricted to the small noise regime). This is used with a Bayesian Optimization procedure, using a number of different types of acquisition functions, to generate informative paths that take uncertainty into account.



Results

Initial experiments show that even with a low-cost and resource-constrained platform, it is possible to perform practically useful operations such as localising sources in a field with multiple modes in the spatial distribution. Moreover, this can be achieved in a three-dimensional environment with the UAV, which extends beyond what has conventionally been possible with ground based systems on which similar active sensing procedures have been implemented in the past. On the sensing side, our initial experiments have demonstrated that it is indeed possible to devise a lower-cost broadband Fourier Transform Spectrometer that can detect gas concentration.



Impact

This work, which is funded by the Defence Science and Technology Laboratories, is aimed at usage in hazardous field environments. An example of an application where this could find use is the UK government's Chemical, Biological, Radiological and Nuclear Defence response teams. The work reported here was completed through a CDE Phase 1 project, with a Phase 2 application currently being considered at the time of writing.

This work has also benefitted from and contributes to a collaboration with DroneDeploy, creators of an industry leading platform for capturing imagery, processing maps and 3D models, and interpreting data. One of the deployment pathways for this work is as an application that interfaces with software such as from DroneDeploy, targeting applications ranging from agriculture to construction.

Future Work

Ongoing work is aimed at extending the algorithms to accommodate spatial and temporal variation, and on planning paths based not just on the uncertainty in field estimates but also on motion costs including battery consumption/life and the expected temporal variability in the field. On the sensing side, our collaborators are keen to improve the sensing resolution that can be obtained in flight (where aircraft vibration can make it very hard for the optical system to function), and to push the concentration measurements down to low concentrations.

Research Area: Cognitive Robotics

Learning to understand symbols from cross-modal sensorimotor experience

Supervisor: Dr Subramanian Ramamoorthy
PhD students: Svetlin Penkov, Yordan Hristov, Alejandro Bordallo

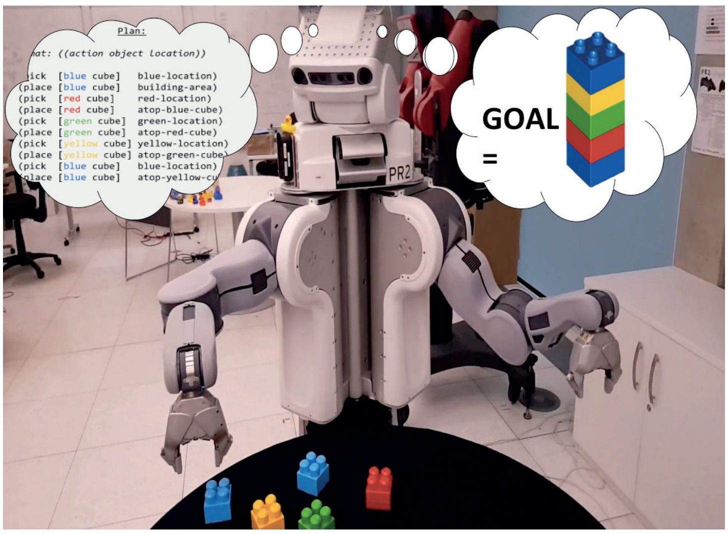
Objectives

The overarching goal of our work in this area has been to bridge the gap between the levels of coarseness with which people conceptualise and talk about tasks, and the level of detail at which robots act and perceive the world around them. Much of the difficulty of co-work in a Human-Robot Interaction setting arises precisely because of the mismatch in representation between the human user and the robotic agent. Through a combination of doctoral student projects, we have developed a technology stack that enables physical scene understanding and context-aware planning. This stack has been implemented with the PR2 and Baxter robots, using sensory inputs including environmental and robot mounted cameras and 3D eye tracking for the human user.

Approach and Results

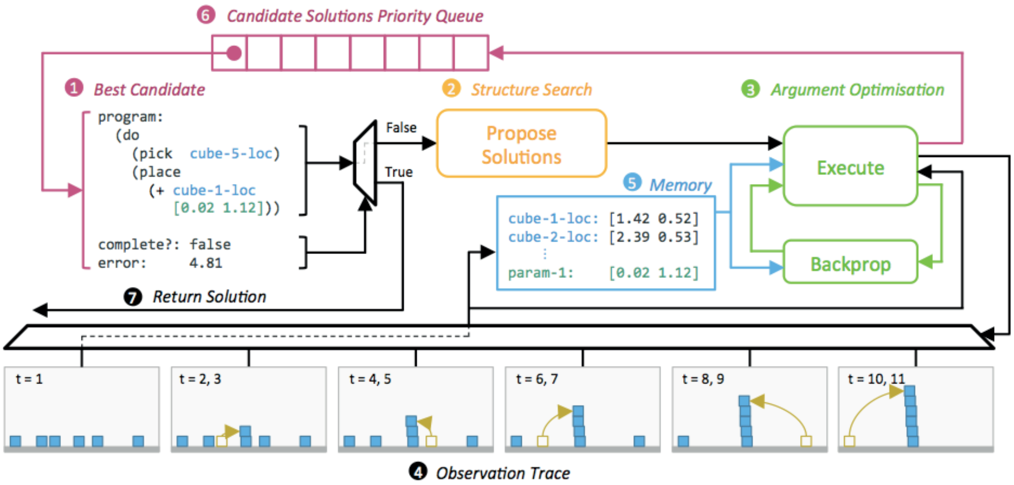
Our work in this area has addressed:
Learning models of objects in human demonstration and task-relevant instructions:

Through a novel framework, entitled GLIDE (Grounding and learning Instances through Demonstration and Eye Tracking) [1, 2], we have shown how to interpret a rich stream of cross-modal sensory signals. This is based on a Bayesian structure learning procedure that exploits the pragmatics of human attentional behaviour to extract movement primitives from video streams. In turn, these movement primitives encapsulate the within-task variability associated with symbols as they appear in natural language descriptions of plans.



Inducing programs that explain the dynamics of transition systems:
We have developed the PI-machine (program induction machine) [3] – an architecture able to induce interpretable LISP-like programs from observed data traces, where the programs represent abstract models capturing invariant structure in the observed data.

As shown in the figure below, this architecture enables us to go directly from observations of the task to programmatic descriptions of the causal structure of the plans. One interesting use of this framework is to explain the behaviour of a Deep Q Network based policy by inducing a functional program with equivalent behaviours.



Impact

The technology stack described here underpins our work within the COGLE project, as part of the DARPA Explainable Artificial Intelligence programme, where the focus is on creating a suite of machine learning techniques that produce explainable models and explanation techniques for next generation human-machine interactive systems. This work has featured in a faculty award to Dr. Ramamoorthy, from the Xerox University Affairs Committee, based on interest in developing methods that work with weak supervision and a sparse set of reinforcement signals (e.g., feedback from human experts) in order to reduce the cost and effort of building machine learning models.

Future Work

These results represent first steps in a programme of work aimed at bringing together the strengths of powerful data-driven learning architectures, such as deep neural networks, and richly expressive models that succinctly capture the nuances of human meaning and intent, to create robots that are genuinely capable of context-aware interactions with human users in homes, hospitals, etc. Major directions of current and future work include the use of this symbol grounding framework to bias reinforcement learning, significantly reducing the sample complexity of these methods to make them actually usable in real time with physical systems, and to use the induced programs in causal reasoning regarding safety and other behavioural properties of interest to system designers.

Publications

S.V. Penkov, A. Bordallo, S. Ramamoorthy, Physical symbol grounding and instance learning through demonstration and eye tracking, IEEE International Conference on Robotics and Automation, 2017.
Y. Hristov, S.V. Penkov, A. Lascarides, S. Ramamoorthy, Grounding symbols in multi-modal instructions, Language Grounding for Robotics Workshop, Annual Meeting of the Association for Computational Linguistics (ACL), 2017.
S.V. Penkov, S. Ramamoorthy, Using program induction to interpret transition system dynamics,, In Proc. ICML Workshop on Human Interpretability in Machine Learning (ICML-WHI), 2017. Runner-up for Best Paper Award

Research Area: Shared Autonomy/Motion Planning/Perception

Robust Shared Autonomy for Mobile Manipulation in Extreme Environments

Supervisor: Professor Sethu Vijayakumar
PhD student(s): Wolfgang Merkt, Yiming Yang, Theodoros Stouraitis, Christopher E. Mower

Objectives

The level of autonomy of a robot is directly correlated with the predictability of the task and environment. Robots executing a predictable task in a foreseeable environment such as in a factory setting work fully autonomous, while for field robots where variance is high, teleoperation is still the accepted gold standard with the human as the decision maker and the robot acting as an extension of the human operator. Many applications in industry are repetitive and require high levels of concentration and manual dexterity, often coupled with the human operator solely performing scene monitoring as well as hazard detection and prevention. As such, the operator is prone to fatigue that has been linked to serious accidents in the past.

In our work, we focus on making robots more flexible and autonomous in challenging real-world environments by
a) Allowing the operator to specify high-level behaviour through intuitive user interfaces;
b) Leveraging a versatile, model-free perception suite;
c) Empowering the operator with assistive and intuitive tools, and reducing fatigue by autonomous task deduction, planning, execution, and scene monitoring;
d) Providing interactive visualisation tools that allow for a blend of assisted teleoperation, shared autonomy, and fully autonomous sequences; and
e) Enabling safe operation in shared workspaces through low-fidelity communication links.

Approach

We developed a fully integrated system for reliable grasping and manipulation using dense visual mapping, collision-free motion planning, and shared autonomy. The motion sequences are composed automatically based on high-level objectives provided by a human operator, with continuous scene monitoring during execution automatically detecting and adapting to dynamic changes of the environment. The system can automatically recover from a variety of disturbances and fall back to the operator if stuck or if it cannot otherwise guarantee safety. Furthermore, the operator can take control at any time and then resume autonomous operation. Our system is flexible to be adapted to new robotic systems, and we use it across a variety of fixed- and floating-base platforms in shared workspace scenarios: industrial robot arms, mobile bimanual manipulators, and humanoids.

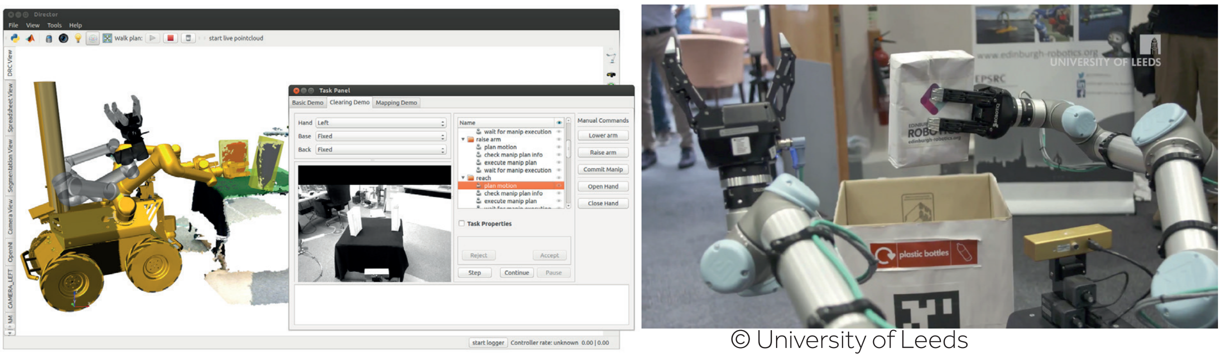


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Figure 1: *Left:* The shared autonomy user interface with live sensor and motion plan visualisation. *Right:* Our bimanual mobile manipulator manipulating an object.

Result

- The proposed shared autonomy system has been demonstrated to complete tasks with minimal high-level user input operating autonomously for the majority of the execution. It can deal with dynamic changes, such as updates of the target affordance or bin location, as well as an obstacle or human entering its shared workspace by safely pausing, replanning, and resuming motion execution.
- Our scene monitoring can be added on top of many motion planning and execution pipelines and runs at 20 Hz, which is responsive enough for operation on a moving platform.
- Selecting a suitable mobile base position improved autonomy robustness and adaptability to changes by maximising manipulability. Using the state-of-the-art iDRM algorithm developed in the Centre enabled real-time, interactive end pose queries during both teleoperation as well as increased robustness for our autonomous runs.

Impact

- First Prize, Greatest Potential for Positive Impact, Robots for Resilient Infrastructure Challenge
- Featured e.g. on BBC Scotland and Made In Leeds TV

Future Work

In our future work, we will investigate safe continuous motion adaptation and local replanning of motion trajectories in response to environment changes, and to incorporate motion flow and predictive tracking of targets and obstacles. We will furthermore emphasise the optimality of motion adaptation for more time- and energy-efficient behaviour exploiting the system and environment dynamics.

Publications

W. Merkt, Y. Yang, T. Stouraitis, C. Mower, M. Fallon and S. Vijayakumar, “Robust Shared Autonomy for Mobile Manipulation with Continuous Scene Monitoring”, 13th IEEE Conference on Automation Science and Engineering (CASE). 2017.

More information on our Robust Shared Autonomy work including videos:
http://bit.ly/robustsharedautonomy

Research Area: Swarm Robotics

Application of Swarm Intelligence techniques in the coordination of a Fleet of Flying Drones using the Robot Operating System

Supervisor: Dr Mauro Dragone, Dr Patricia A. Vargas
PhD student(s): Hugo Ricardo Meireles Sardinha

Objectives

The aim of this project is to develop an open source research platform for aerial swarm robotics. Producing effective ways to control swarms of autonomous flying drones offers many opportunities to exploit robotic autonomous system (RAS) technology in a wide range of application domains, from environmental monitoring, to first response and search-and-rescue missions. However, despite the rapid proliferation of easy to make, cheap to buy, and simple to fly available drones, it is still difficult to study swarm control techniques in realistic application scenarios. Furthermore, current research provides little insight on how to assess the performance of different implementations.

Approach

This approach is focused on investigating the use of the robotic operating system (ROS) in conjunction with off-the-shelf drones.
The use of ROS is motivated by the need to build modular software systems to simplify the integration of existing algorithms and promote flexible code re-use. The approach involved a requirement analysis of suitable control architectures, especially bio-inspired ones exploiting de-centralised coordination mechanisms for their ability to deliver robust and scalable systems. Quantitative metrics for the evaluation of typical swarm behaviours were also investigated. The analysis informed the development of a software framework that is able to support the operation and the benchmarking of swarms of drones as well as their simulation by combining the ROS-Gazebo suite [1] with open-source control software based on the Ardupilot software [2].

Results

The software combines the existing components and adapts them to support the portable instantiation and the communication among control systems for multiple drones. A proof of concept evaluation of the framework was provided by implementing and testing a state-of-the art flocking behaviour [3] using the Gazebo 3D simulator. The flocking control strategy was tailored to the flying and sensing capabilities of a commercial, off-the-shelf drone (the ERLE quadcopter, in Figure 1). Figure 2 is a snapshot from a simulation of 5 drones flying in formation. A video of the simulation can be viewed at https://www.youtube.com/watch?v=hVe3ht-fOtw

Figure 1: ERLE quadcopter
Image © ERLE Robotics
See https://erlerobotics.com/blog/product/erle-copter-diy-kit/

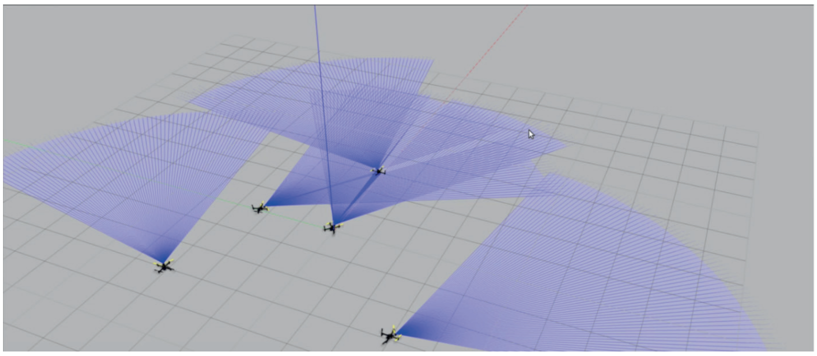


Figure 2: snapshot from simulation of 5 drones flying in formation.

Future Work

Future work will leverage and extend the framework and the benchmarking suite to investigate suitable optimisation and control techniques able to address dynamic mission objectives and communication and other constraints encountered in realistic application scenarios.

Impact

Work is underway to publish all the parts of the framework, including extensions to ROS-Gazebo and ArduPilot plugins. This will support the research community by helping to bridge the gap between the research in high-level swarm control strategies and their practical implementation, and will serve as a test-bed and benchmark tool for other multi-UAV systems. The suite of metrics will help researchers to design and gain insight on the effectiveness of their systems, in an easily accessible manner, thus creating a strong foundation for future work.

References

[1] ROS Gazebo package summary, http://wiki.ros.org/gazebo, (Accessed on 8/28/2017).
[2] ArduPilot Open Source Autopilot, http://ardupilot.org/, (Accessed on 8/28/2017).
[3] Craig W Reynolds. Flocks, herds and schools: A distributed behavioral model. In ACM SIGGRAPH computer graphics, volume 21, pages 25-34. ACM, 1987

Research Area: Swarm Robotics

Hamilton - A Novel Open Swarm Robotic Platform for Search and Rescue Applications

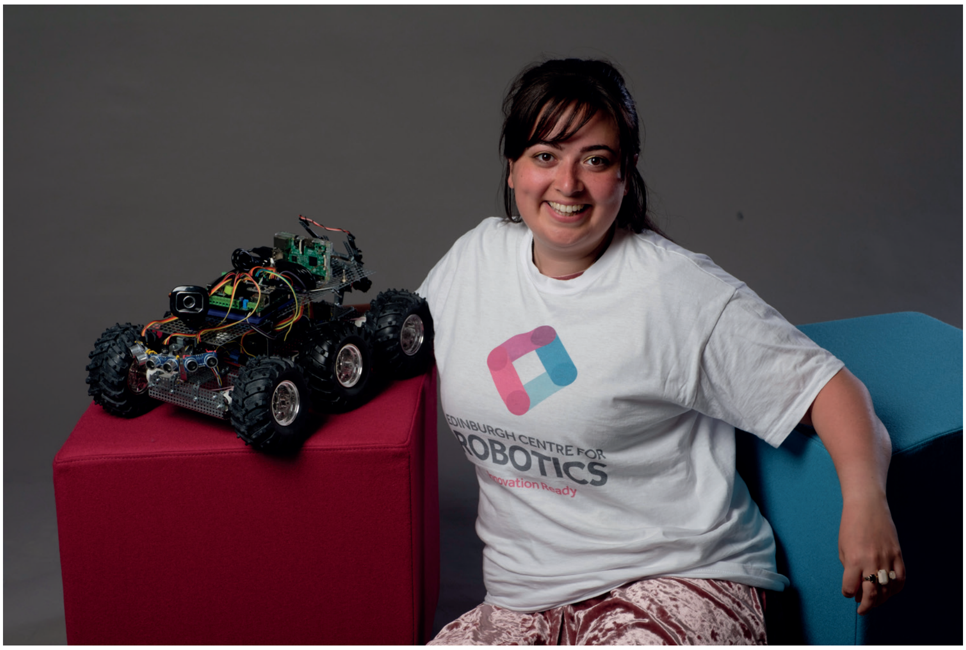
Supervisor: Dr Mauro Dragone, Dr Patricia A. Vargas
PhD student(s): Siobhan Duncan

Objectives

The goal of this project is to develop a novel open source robot platform to boost research in swarm robotic techniques for search and rescue applications. Swarms of robots small enough to enter confined spaces can save lives while keeping rescue workers safe by entering and collaborating in the exploration of damaged areas to find those in most urgent need of attention. Current platforms focus on facilitating table-top experimental environments and we lack open and cost effective test-bed that can be used to investigate robotic swarm techniques in realistic settings.

Approach

A requirement gathering step was used to capture typical mobility, perception and communication characteristics of robots for search and rescue scenarios. A survey of 50 robotic platforms for swarm robotic research was also conducted. The new platform was designed to fill a gap in current propositions by targeting a low-cost, open source and easy-to-use solution to conduct research in bio-inspired (ant-like) coordination of swarm systems suitable for large-scale search and rescue missions.



Results

Figure 1 is a picture of the developed prototype, named Hamilton. Hamilton is a 6-wheeled differential drive battery-powered robot. Its ability to move up and down each wheel allows it to deal with a diverse range of terrain and obstacles. The robot is equipped with sonars, accelerometer, 3-axis giroscope, GPS, pan & tilt camera, and communication modules for RF, WiFi and Bluetooth. Furthermore, a led array at its rear can be used to provide visual feedback to human operators and also to serve as a local communication medium among robots. The robot has a two tier hierarchical computing architecture: a microcontroller (ARM MBED) is used to interface sensors, communication modules and to provide re-usable low-level task primitives, while a raspberry PI is configured for over-the-air programming of decision making and high-level functions such a localisation, mapping, and image processing.

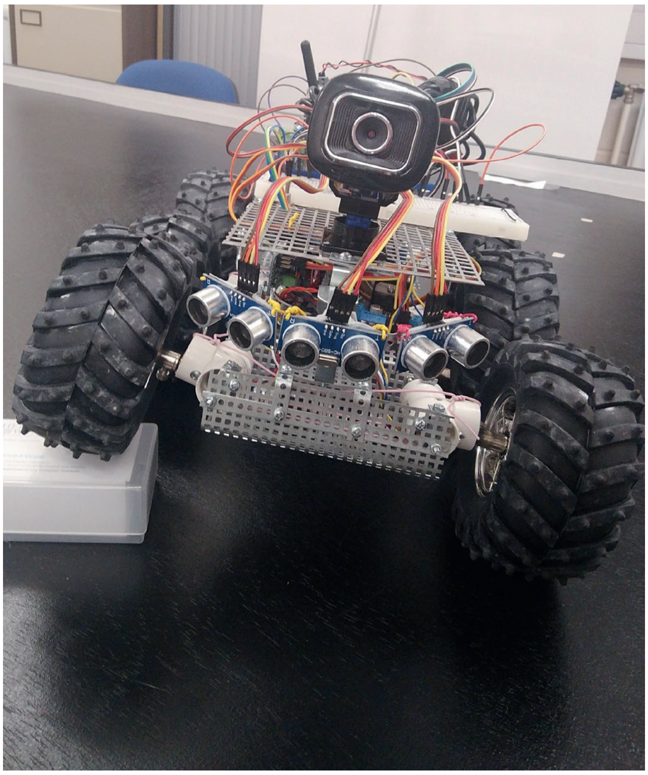


Figure 1

Impact

Work is underway to publish the design of the hardware and all the software components to the open source community. The use of the robot's design will be offered in undergraduate projects, to swarm robotic researchers, and promoted as an educational tool.

Future Work

Future work will leverage the new platform to investigate bio-inspired swarm robotics techniques in the context of realistic search and rescue scenarios. To this end, Hamilton's design will be further improved, by 3D printing some of its parts, fitting more powerful motors, enabling autonomous recharging operations, and by integrating its software system with the Robot Operating System (ROS) and Gazebo 3D simulator toolset.

Research Area: State Estimation and Mapping for Bipeds and Quadruped Robot

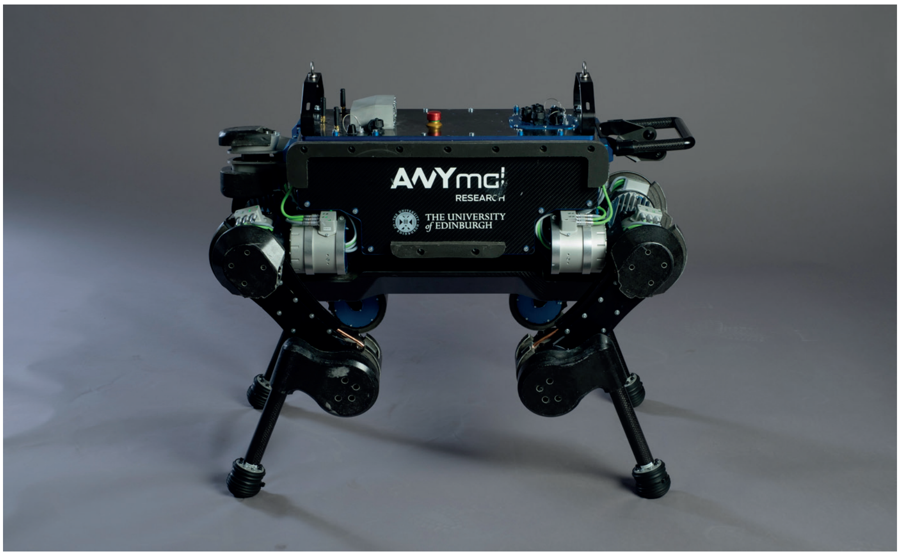
Quadrupedal Locomotion and State Estimation using the HyQ robot

Supervisor: Dr Maurice Fallon
PhD student(s): Simona Nobili and Raluca Scona

Objectives
To develop autonomy or to achieve reliable feedback control on walking robots it essential to have accurate state estimation. These robots often have redundant sensing, the challenge is to robustly fuse these sensor readings to achieve such performance. This work is in collaboration with the Italian Institute of Technology.

Approach
Central to our is probabilistic sensor fusion of different source: inertial sensing from the robot's accelerometers and gyroscopes, kinematic information from its joints and contact sensors as well as external sensing such as LIDAR and vision sensors.

Result
Accurate localisation of the HyQ quadruped trotting forwards and backward in a 20m long experiment in an badly lit industrial environment. The NASA Valkyrie can now build dense maps by combining proprioception with stereo vision.



Impact
This is a key enabling technology to allow the robot to operate outdoors and in the field. These algorithms will be used when a new version of the HyQ, HyQ-Real, takes its first steps outdoors in 2018.
RSS 2017 Student Travel Award Winner: Simona Nobili

Future Work
Extension of the described works for more challenging conditions. Adaptation to enable visual path following by quadrupeds such as the HyQ and the AnyMAL. Exploration of localisation without external sensing – using only contact information

Publications
Probabilistic Contact Estimation and Impact Detection for State Estimation of Quadruped Robots, Marco Camurri, Maurice Fallon, Stephane Bazeille, Andreea Radulescu, Victor Barasuol, Darwin G. Caldwell, Claudio Semini, Robotics and Automation Letters, April 2017.

Overlap-based ICP Tuning for Robust Localization of a Humanoid Robot, Simona Nobili, Raluca Scona, Marco Caravagna, Maurice Fallon, IEEE International Conference on Robotics and Automation 2017, Singapore.

Heterogeneous Sensor Fusion for Accurate State Estimation of Dynamic Legged Robots,Simona Nobili, Marco Camurri, Victor Barasuol, Michele Focchi, Darwin Caldwell, Claudio Semini and Maurice Fallon, Robotics: Science and Systems 2017. Cambridge, MA.

Direct Visual SLAM Fusing Proprioception for a Humanoid Robot, Raluca Scona, Simona Nobili, Yvan Petillot and Maurice Fallon, IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS), 2017. Vancouver, Canada.

Research Area: Machine Learning, Industrial Robotics

Learning Constrained Policies by Demonstration for a Wiping Task

Supervisors: Dr Mustafa Suphi Erden, Professor Sethu Vijayakumar
Postdoctoral Researcher: Dr Vladimir Ivan
PhD student: João Moura

Objectives

We humans have a remarkable capability of adapting our actions and motions to the environment we interact with. One particular example, illustrated in Figure 1, is wiping the surface of a train during its cleaning. The operator is able to apply the same wiping strategy/motion regardless of the train's surface geometry and orientation.

With the goal of employing robots in such challenging scenarios, we would like to develop controllers that mimic the human motion for executing such tasks, in the form of behaviours that we call control policies. Learning control policies from expert to a robotic system. However, in this project we also aim at capturing some of the human demonstration is an effective way of transferring that knowledge from a human versatility, i.e., the operator ability to employ a similar wiping motion to different train surfaces.

Fig 1: Manual Cleaning of an Electric Train. Willesden Depot, London (2016)

We model the surface as a constraint to the wiping motion. Our aim is to learn a policy that can generalize to unseen constraints, from the ones used during the demonstration.

Approach

The approach is based on the assumption that when the demonstrator executes an action in a constrained environment, there is an underlying unconstrained policy. We learn this unconstrained policy so we can generalize it to different constrained environments. The challenge, however, is that the data is collected under different unknown constraints and, therefore, the collected actions are not directly generated by the policy we wish to learn.

The learning approach starts by modelling the actions as a decomposition of a primary task space component and a secondary task. The primary task ensures that the constraint is satisfied. In the case of the wiping application, it is to maintain the contact with the surface while wiping. The second task is the result of projecting the unconstrained policy into the tangent space of the primary task. We call this the null space. This ensures that the second task, such as circular wiping, does not interfere with the primary task.

The method developed in this work is a computationally efficient method that splits the learning process in a 2-stage process: at the first stage, we estimate the constraint for each demonstration, and at the second stage we use the estimated constraints to learn the unconstrained policy.

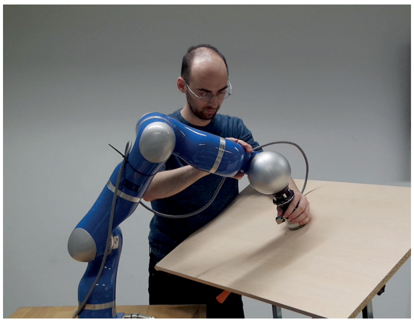


Fig 2: Demonstration of a circular wiping trajectory on a flat surface. The demonstrations were repeated for multiple orientations.

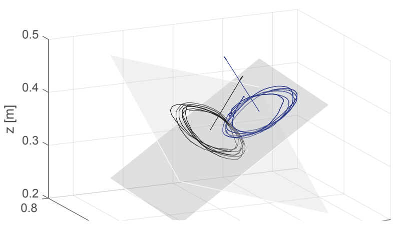


Fig 3: Two samples of the generated wiping trajectories from human demonstrations.

Results

To test the proposed method, we collected the robot data from demonstrations of a set of circular wiping motions for different planar surface orientations, as in Figure 2. This data consists on the robot state - joint positions - and the robot actions - joint velocities. Figure 3 shows the corresponding wiping tool positions for 2 of the demonstrations, as well as the estimated surfaces' normal.

We then reproduced the learned policy for wiping a non-flat surface where the primary task is accomplished by using a force/torque sensor to align the tool with the surface, as in Figure 4. The constrained motion along the surface is a combination of the unconstrained policy learned by demonstration and the new unseen constraint given by the surface geometry, resulting in the trajectory shown in Figure 5.

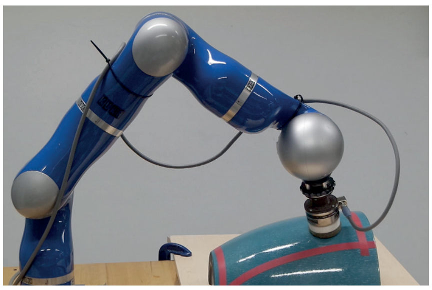


Fig 4: KUKA lightweight robotic arm equipped with a force/torque sensor executing the learned wiping policy.

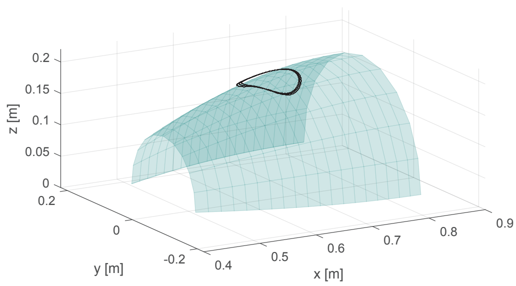


Fig 5: Resulting trajectory from policy generalisation to the non-flat surfaces using a force-sensor task to align the tool dynamically.

Future Work

Future work will include extending the current learning method to the dynamic case, i.e. being able to learn the robot torque controls when performing a constrained task. This would be useful for applications that require rigid interaction between the robot and the environment, where the robot has to be torque controlled.

Publications

Moura, J., Erden, M. S. (2017). Formulation of a Control and Path Planning Approach for a Cab Front Cleaning Robot. Procedia CIRP, 59, 67-71. DOI: 10.1016/j.procir.2016.09.024

Armesto, L., Moura, J., Ivan, V., Salas, A., & Vijayakumar, S. (2017). Learning Constrained Generalizable Policies by Demonstration. In Proceedings of Robotics: Science and System XIII. DOI: 10.15607/RSS.2017.XIII.036

Research Area: Assistive Robotics

Quantitatively Measuring Laparoscopic Skills for Robotic Training and Assistance

Supervisor: Dr Mustafa Suphi Erden
Research Associate: Dr Harun Tugal

Objectives

The aim of this project is to capture surgeons' manipulation skills quantitatively in the course of Minimally Intensive Surgery (MIS) by analysing tool position and hand-impedance. Thus, more effective training techniques can be put into practice with a co-manipulated robot trainer.
The first aim is to distinguish skilled plain tool movements from the non-skilled ones. The identification process is based on the tool position measurements while professional and trainee subjects are carrying out experimental MIS. By comparing the manipulation of the professional and trainee subjects, it will be possible to develop quantitative measures of detection and recognition of skilled versus unskilled tool movements. The second objective is to obtain knowledge of hand-impedance of the skilled hand manipulation in MIS. In order to accomplish that within the MIS, which requires complex hand manipulations, an impedance measurement scheme will be developed. The proposed scheme needs to estimate the intended hand movements and apply position disturbances and register real time measurements in order to compute the hand-impedance. Based on the gained knowledge, a co-manipulated robotic training platform can be implemented such that through detection of unskilled movements the system provides notice feedback to the trainee about undesired hand and arm movements by means of visual and/or audio alerts. The trainee, then, would aim to minimize the frequency of these alerts so subjects are likely to learn how to avoid unskilled hand movements.

Approach

To achieve the mentioned objectives we have been using two UR3 robot arms under an admittance control law. A force/torque sensor has been inserted between the robot's end-effector and a special mechanical adaptor which was integrated to the MIS tool. Fig. 1 illustrates the established platform where the robot and a MIS training kit have been integrated. As an assister, the robot operates in the passive control mode and intervenes actively for co-manipulation only either for measurement purposes or to assist the subject in an appropriate fashion. The control diagram of the admittance controller for the co-manipulation is illustrated in Fig. 2.
Hand impedance measurement schema will incorporate real time estimation of the hand movement in order to perform adequate and appropriate disturbances to the operator based on the operation phase. The movement features will be identified by using available measurements within the system such as position, velocity, and force/torque information. For comparison, data will be collected from various operations carried out by professional versus trainee subjects.

Result

The subsequent figures illustrate the experimental setup that contains interconnected MIS training kit with one of the UR3 robots and the block-diagram of the admittance control architecture for co-manipulation.

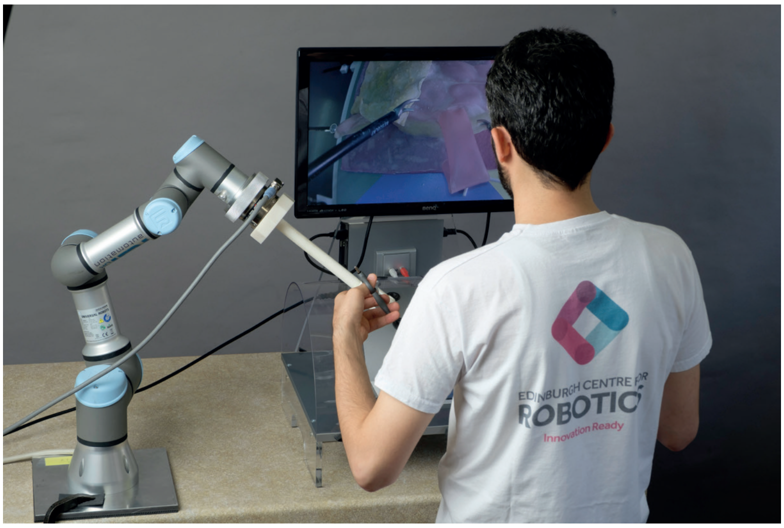


Fig.1: Experimental setup where robot is integrated with the MIS kit via force/torque sensor and the mechanical adaptor.

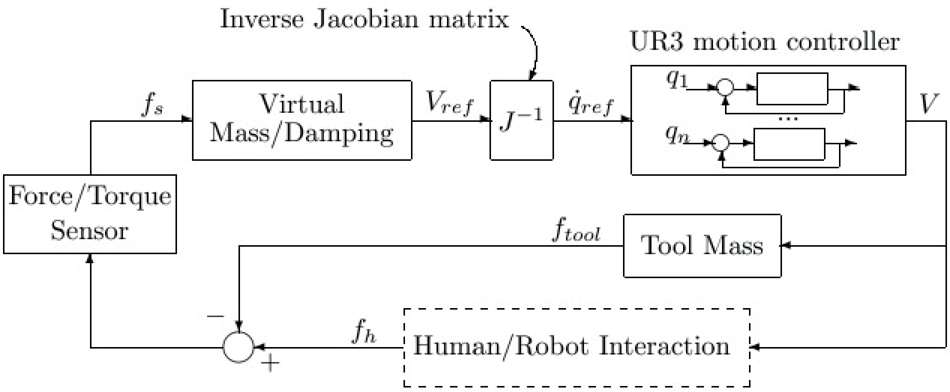


Fig. 2: Block diagram representation of the implemented admittance controller.

Impact

This project will make a significant contribution not only to robotic assistance and training for MIS applications but also to a variety of industrial manipulation tasks where complex hand manipulation is required to accomplish dedicated duties. Specifically, this project will develop means of quantified measure of skill for such complex hand manipulation tasks.

Research Area: Humanoid Robotics

Whole-body Control of Dynamic Locomotion for Humanoid Robots

Supervisor: Dr Zhibin Li
PhD students: Iordanis Chatzinikolaidis, Qingbiao Li

Objectives

Legged locomotion is one of the most fundamental problems for roboticists that remains largely unsolved. For us, humans, walking and running are intuitive skills. But the fundamental mechanisms behind these biological processes are still obscured even after many years of intensive research. Thus, the proper implementation of efficient walking algorithms–especially in bipedal robots–is a topic that attracts greater attention as robots become more pervasive in our daily lives.
Walking in regular ground and level surfaces is a mature research topic where several solution approaches have already been proposed with fruitful results. But when the gait stops being cyclic and the ground exhibits height variations and inclinations, the assumptions behind most proposed solutions are violated and therefore fail. Our objective is to design a planning and control approach that will be able to effectively cope in the presence of such situations.

Approach

While planning a motion and then controlling the robot to execute the plan as close as possible is the traditional paradigm–with the former preceding the latter–, we strive to closely relate these two approaches by sharing information between the status of the robot and the plan for the next few actions. The main challenge is to successfully perform all the intensive calculations required given the strict time limits. We believe that the following points constitute a reasonable perspective for tackling the problem:

- We calculate the minimum required forces in order to execute the desired motions, while satisfying all necessary constraints; if they cannot be satisfied, we try to come as close as possible and lead the robot in a state that will allow satisfaction in the future.
- Instead of searching for the best possible place for the robot's hands and feet that would produce the required forces, we opt for selecting ones which may not be globally optimal, but which will allow us to execute the requisite motion within safety limits.
- The robot reasons for the next few moments and not for the whole duration of the motion. As a result, computation is much lighter and the robot can re-plan in the case of unexpected changes; a common situation outside the laboratory settings.

Result

For calculating the robot motion given a set of constraints, we are developing a method which leverages results from optimisation theory with recent advances in the control of dynamical systems. This way we calculate the required forces from the environment alongside the movement of the robot using methods that achieve much faster computation times than standard techniques. By relying more on insights of the physics rather than blind out-of-the-box methods, we solve the problems at hand with a much higher fidelity than the common approaches.

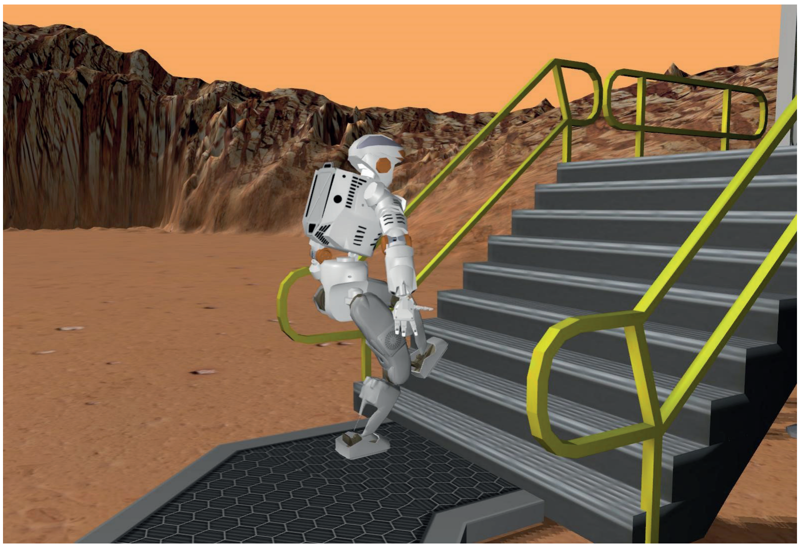
Impact

We hope that by obscuring the boundaries between planning and control, humanoid robot locomotion can become more efficient and agile, without necessarily sacrificing safety. While the current methods are very conservative–mainly for safety reasons–, we argue that by entangling planning and control, robots can achieve a greater variety of motions. As bipedal locomotion is more unstable and demanding than four- or six-legged locomotion our approach can be applied to legged robots in general.

Qingbiao Li, Iordanis Chatzinikolaidis, Yiming Yang, Sethu Vijayakumar and Zhibin Li, Data-based Optimisation for Adaptive Foot Placement in Dynamic Legged Locomotion, 2017 IEEE-RAS International Conference on Humanoid Robots, Birmingham, UK (2017)

Future Work

Our next big goal is to formulate the contact location search in a more structured and systematic way. Computation times of current methods are prohibitive for real-time applications, so we will shift our focus on strategies that can make this possible. Finally, a missing piece is the experimentation on our robot Valkyrie, which will ultimately validate the results of our research.



Valkyrie ascending stairs during an operational scenario.
Image recorded using srcsim simulation platform
(https://bitbucket.org/osrf/srcsim).

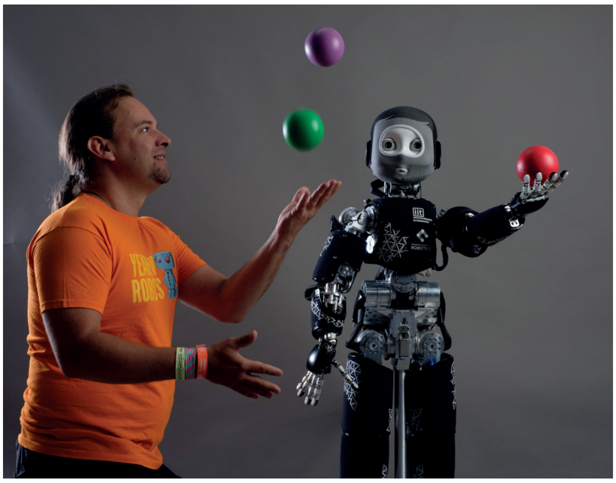
Research Area: Human-Robot Interaction

Enhanced Recognition and Contingent Behaviour for HRI

Supervisor: Dr Katrin S. Lohan
PhD student: Ingo Keller

Objectives

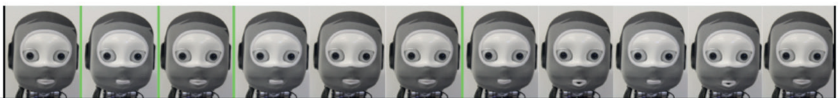
With the recent advances in robotics, computer vision and machine learning, robot companion systems have started to appear in private homes. Whilst this may lead to the availability of personal robotic assistants, the research into long-term engagement with these systems is still in its early stages. One major obstacle is the real world environment, which is less controllable than a lab environment and therefore raises new challenges to established methods. Also, Human-Robot Interaction (HRI) is facing several barriers whilst moving out of the lab environment into the real world. One of these barriers is to detect, understand and learn from natural interaction with humans.



In our research, we are addressing the two sides of interactions. On one hand, we are working towards a more robust perception in real world environments in order to increase the capabilities of humanoid robots to operate under every day conditions. At the same time, we are investigating on appropriate robot behaviours and expressiveness to facilitate a more natural interaction between robots and humans. We focus our research on the robot iCub as an example of a humanoid robot companion platform.

Approach

We developed methods to increase the visual recognition for objects and actions on the iCub by means of data augmentation. We use intrinsic information (already captured data) and extrinsic information (influencing the human behaviour to be more expressive) to increase the recognition during the Human-Robot Interaction.
To investigate on visual perception, we looked at the problem of illumination change robustness and showed the impact using linear and non-linear models on state-of-the-art recognition methods (Figure 1). Furthermore, we proposed a training sample selection strategy to enhance the recognition for objects for real world scenarios.
We also developed the Lip Synchronization for the iCub in order to increase the likeability of humanoid systems and therefore increase the engagement with the robot. An example of the produced viseme-phoneme mapping and their timing is shown below.



iCub talking head													
phrase	I	am		a	face			robot					
phonemes SAMPA	AI	{	m	@	f	EI	S	r	@U	b	A	t	**total in ms**
duration in ms	160.0	12.7	78.9	28.8	130.3	134.4	66.5	181.9	141.8	63.1	57.2	124.8	1180.4

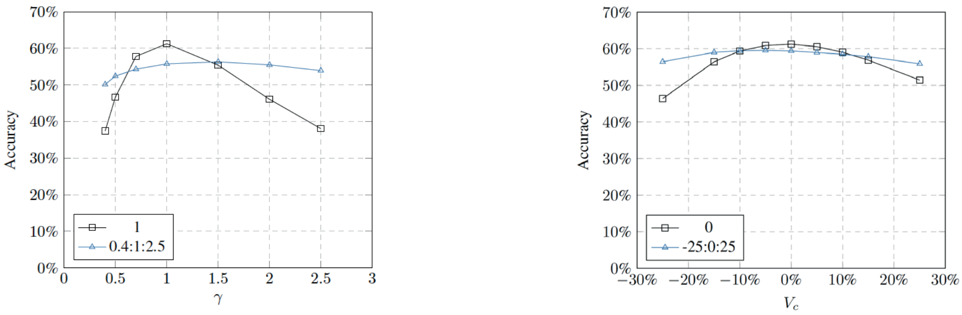


Figure 1: Influence off modification changes: Using non-linear (left) or linear (right) modified training samples the blue line shows the increase in recognition accuracy towards the extreme values.

Result

With our method for data augmentation, we were able to increase the recognition rate of the object recognition for the iCub robot from 69.4% to 88% under real world illumination changes. Additionally, we have shown, that social robots that show contingent behaviour can shape the human's behaviour to become more expressive and therefore easier to recognise for the robot. This information can help particular for the development of action recognition methods.
Also, we provided the Lip Synchronisation for different iCub heads, particular for the iCub talking head, as open source to be used by the iCub community.

Impact

Instead of developing new, often computationally expensive recognition methods, we have shown how to employ different types of data augmentation. We could show that data augmentation is a viable way to increase the perception capabilities of robot companions by enhancing state-of-the-art recognition methods.
The Lip Synchronisation module for the iCub can now serve as a tool to investigate on the impact of the visual cue for differentiating of phonemes (McGurk effect) in social interactions. It also increases the likeability of the robot which increase the engagement of participants in experiments and therefore supports HRI research using the iCub in general.

Future Work

There is still a lot of work to be done before interactions with social robots are as natural as Human-Human Interactions. The next step for a better recognition of the robot's environment is to take context into account. In order to do so, the robot needs to abstract from low level input to higher level symbolic representations to be able to use inferred contextual knowledge. The recognition could benefit from a decreased search space using this knowledge.

Publications

I. Keller, K. S. Lohan, "On the Impact of Illumination for Long-Term Object Learning in Robot Companions", IEEE TCDS (under review)
I. Keller, K. S. Lohan, "Analysis of Illumination Robustness in Long-Term Object Learning", IEEE ROMAN 2016
I. Keller, M. Schmuck and K. S. Lohan, "Towards a model for automatic action recognition for social robot companions", IEEE ROMAN 2016
I. Keller, K. S. Lohan, "Lip synchronisation for the iCub talking head", IEEE ROMAN 2016
H. Lehmann, I. Keller, R. Ahmadzadeh, F. Broz, "Naturalistic Conversational Gaze Control for Humanoid Robots - A First Step", ICSR 2017 (in press)

Research Area: Assistive Robotics

Robotic Assisted Drawing

Supervisor: Dr Mustafa Suphi Erden
PhD student(s): James Horn

Objectives

This research builds upon the work carried out by Dr Erden on robotic assistance for welding and airbrush painting, with the aim of developing his work towards robotic assistance for drawing/writing on a notepad and then to investigate the effects that certain parameters have on the assistance provided.
There have been three objectives:
1. to design a new task that allows for easily repeatable experimentation without specialist equipment;
2. to implement admittance control for co-manipulation with a KUKA LBR iiwa 14 arm;
3. to build upon the co-manipulation control framework to produce assistive forces using virtual mass, stiffness and damping.

Finally, the long term research goal is to develop dedicated experiments in order to test and analyse the impact of the mass, stiffness, and damping parameters on the co-manipulation assistance and to optimize these values adaptively for each subject using the system.

Approach

The first stage was to identify an alternative task to the welding and airbrush painting used in the previous work. The new task had to require less specialised equipment, be cleaner, more easily repeatable and not require a constant supply of expensive input material. A series of adaptors then had to be designed and 3D printed to connect the flange of the KUKA arm to a force sensor, and the force sensor to the tool required for the new task. A set of template images compatible with the new task also had to be created, along with code to perform image processing to determine the difference between the template and the drawn image.
The second stage was to use ROS to implement admittance control by reading data from the force sensor and the KUKA arm and using it to determine the next position. The data was also stored so that it could be analysed after an experiment.

Figure 1: Experimental set-up

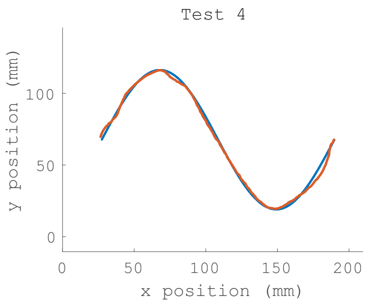


Figure 2: Example result from admittance control showing the drawn and template lines

Result

Currently we have implemented the admittance control scheme for co-manipulation and applied it to the task of drawing on a notepad in the control of a human user. The new task uses a touch screen stylus with a suspension system to draw on a tablet that has a drawing application installed, the experimental set-up is shown in Figure 1. The template images are loaded onto the tablet, the user traces the template line, and the drawn image is saved. In the admittance control mode, the user holds the tool adaptor and attempts to copy the template line, an example of which is shown in Figure 2.

Future Work

The next step in the research is implementing the assistive forces and investigating the three parameters to find an optimal combination. Once that framework has been prepared we will apply adaptive and intelligent learning techniques to adapt the values of these parameters to the user in an optimal fashion.

Research Area: Industrial Robotics

Adaptive Robotic Hand

Supervisors: Dr Xianwen Kong, Prof James M Ritchie
PhD student(s): Guochao Bai

Objectives

In recent years, applications requiring industrial assemblies within a size range from 0.5mm to 100mm are increasing due to the large demands for new products, especially those associated with digital multimedia. Research on grippers or robotic hands within the mesoscopic scale of this range has not been well explored. The objective of the research is to develop an adaptive robotic gripper to bridge the gap between micro-grippers and macro-grippers by extending the gripping range to the mesoscopic scale, particularly without the need to switch grippers during assembly.

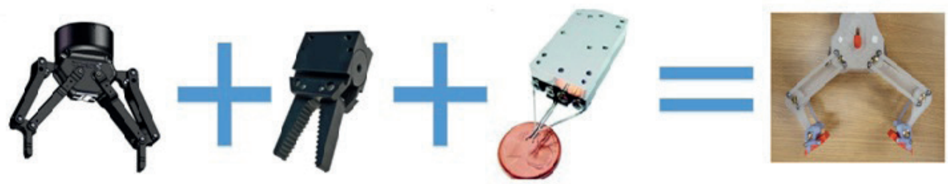


Figure 1

Approach

The passive adjusting and angled gripping modes are analyzed and a dual functional mechanism design proposed. A geometric constraint method is then demonstrated which facilitates the task-based dimensional synthesis after which the kinematics of the synthesized gripper is investigated. Finally, the gripper is optimized according to its stiffness and layout. See Figure 2.

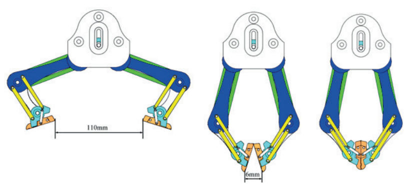


Figure 2

Result

3D printed prototypes are successfully tested and the two integrated gripping modes for universal gripping verified.

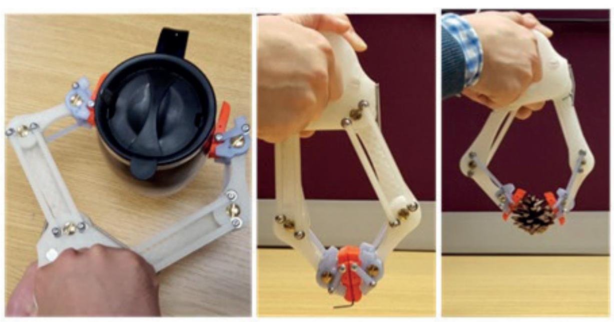


Figure 3 - testing of 3D prototypes

Future Work

Future research will address the gripping force during dimensional synthesis and optimization. Sensors attached to the fingertips will be incorporated to measure the gripping force imposed on objects in the gripper control.

Impact

Bai, G., Kong, X., and Ritchie, J. M. (2017). Kinematic Analysis and Dimensional Synthesis of a Meso-Gripper. Journal of Mechanisms and Robotics, 9(3), 031017.
Bai, G., Kong, X., inventor; Heriot-Watt University, assignee. An improved Gripper. International Patent, PCT/GB2017/052396 (filed on 15 February 2017)

Research Area: Humanoid Robotics

Efficient Humanoid Motion Planning on Uneven Terrain Using Paired Forward-Inverse Dynamic Reachability Maps

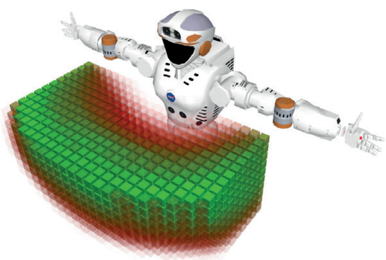
Supervisor: Professor Sethu Vijayakumar
Research Associate: Vladimir Ivan
PhD student(s): Yiming Yang, Wolfgang Merkt, Henrique Ferrolho

Objectives

A key prerequisite for planning manipulation together with locomotion of humanoids in complex environments is to find a valid end-pose with a feasible stance location and a full-body configuration that is balanced and collision-free. Prior work from our laboratory based on the Inverse Dynamic Reachability Map (cf. Annual Report 2015-16) assumed that the feet are placed next to each other around the stance location on a horizontal plane, and the success rate of the end-pose planning algorithm was correlated with how many samples could be stored in our precomputed data structure, which in turn is limited by the memory available on commodity hardware.

Approach

In this recent work, we present a framework that is a combination of our previous inverse Dynamic Reachability Map and forward Dynamic Reachability Maps (i.e. a Paired Forward-Inverse Dynamic Reachability Map) to exploit a greater modularity of the robot's inherent kinematic structure. The combinatorics of this novel decomposition allows greater coverage in the high-dimensional configuration space while reducing the number of stored samples. This permits drawing samples from a much richer dataset to effectively plan end-poses for both single-handed and bimanual tasks on uneven terrains. This novel method was demonstrated on the 38-DoF NASA Valkyrie humanoid by utilizing and exploiting whole-body redundancy for accomplishing manipulation tasks on uneven terrains while avoiding obstacles.



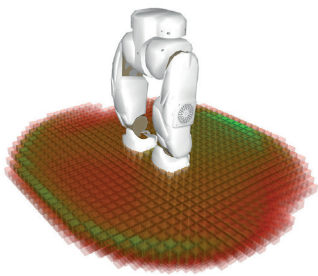


Figure 1:
Left: Visualisation of the precomputed reachable space for the upper-body inverse Dynamic Reachability Map.
Right: Visualisation of the precomputed reachable space for the lower body (Forward Dynamic Reachability Map).

Result

We presented a novel end-pose planning algorithm that combines the Dynamic Reachability Map (DRM) and inverse Dynamic Reachability Map (iDRM), which allows humanoid robots to automatically find appropriate end-poses in presence of uneven terrain. Using NASA's Valkyrie humanoid as a testbed, we demonstrated the effectiveness of the proposed method in planning end-poses for both single-arm and bimanual tasks on uneven terrains.

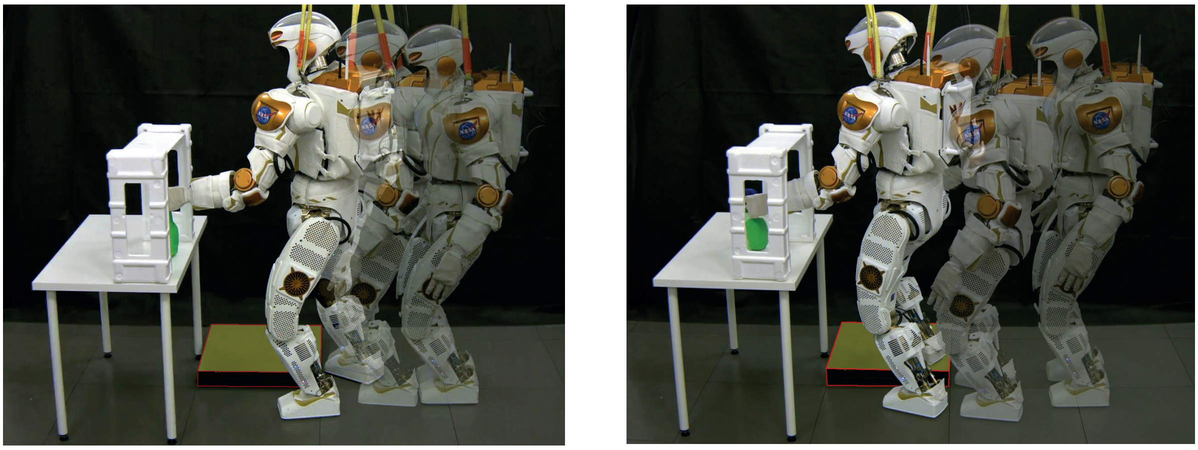


Figure 2: Left: In a restricted non-flat environment, our new method finds a naturally comfortable stance location which independently places the feet from each other resulting in a lunge step while placed on the same surface. Right: With the object placed further into the table, our algorithm determines a step up onto the elevated support surface is necessary to reach the target.

Future Work

We are currently investigating the extension to all terrains, i.e. including support surfaces that are tilted and sloped. This introduces a further challenge for pre-computed solutions as the properties of the support contacts need to be considered during investigation: Will the robot's feet slip at a certain inclination or will the foot placement lead to instability of the posture, e.g. to external disturbances or motion execution?

Publications

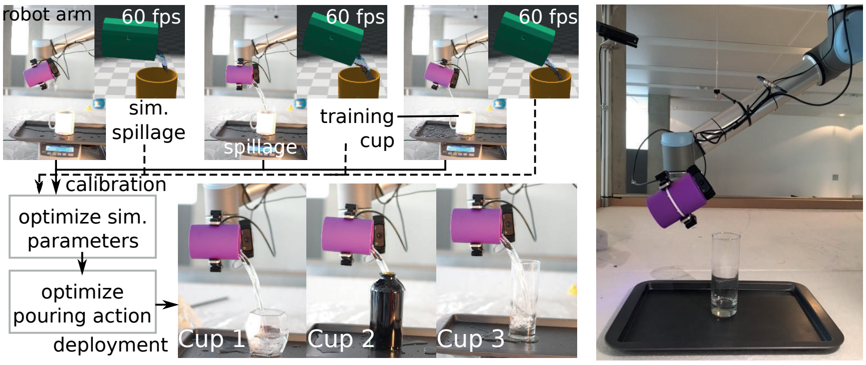
Y. Yang, W. Merkt, H. Ferrolho, V. Ivan and S. Vijayakumar, "Efficient Humanoid Motion Planning on Uneven Terrain Using Paired Forward-Inverse Dynamic Reachability Maps," in IEEE Robotics and Automation Letters, vol. 2, no. 4, pp. 2279-2286, Oct. 2017.
doi: 10.1109/LRA.2017.2727538
Video: https://www.youtube.com/watch?v=o-05EHf-gg8

Y. Yang, V. Ivan, Z. Li, M. Fallon, and S. Vijayakumar, "iDRM: Humanoid Motion Planning with Real-Time End-Pose Selection in Complex Environments," IEEE-RAS International Conference on Humanoid Robots (Humanoids), pp. 271-278, 2016.
Video: https://www.youtube.com/watch?v=e09B-hAVKNs

Research Area: Manipulation

Adaptable Pouring: Teaching Robots Not to Spill using Fast but Approximate Fluid Simulation

Supervisors: Dr Kartic Subr, Dr Subramanian Ramamoorthy, Prof Nicholas K. Taylor
PhD student(s): Tatiana López Guevara



Objectives

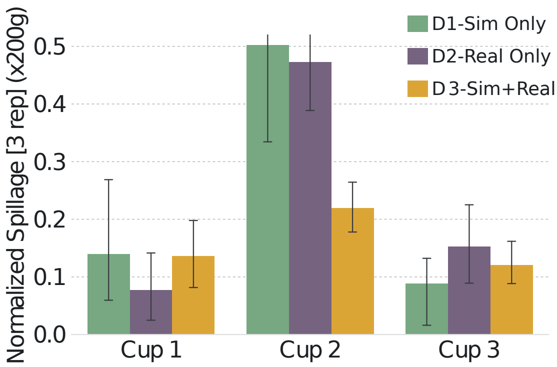
Our goal is to empower robots to perform tasks such as transferring liquids from one container to another without restrictions on the shape of the containers. We achieve this goal by guiding the pouring policy using simulation. Capturing the physics of fluids is a complex modelling problem requiring sophisticated mathematical models. High-fidelity fluid simulation demands heavy computational budget as well as precise sensors. Low-fidelity simulations are feasible, due to their speed, but suffer from problems such as model mismatch since parameters to the simulator may not correspond to physical quantities such as viscosity or density. Nevertheless, recent computational cognitive studies support the idea that humans reason about fluids intuitively using fast approximation of the underlying physical model. Inspired by this, we demonstrate that approximate fluid models can be used to guide pouring tasks performed by a real robot. We also propose a method to overcome the problem of model mismatch in this context.

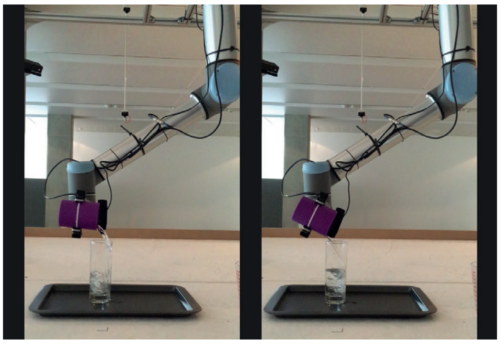
Approach

We attain our goal of minimising spillage by exploiting recent advances in computer graphics for real-time applications (position-based-dynamics). We propose a two-stage adaptable pouring algorithm guided by fast simulation (NVIDIA FleX). In the first stage, we learn optimal simulation parameters inherent to the fluid by minimising the discrepancy between simulated spillage and real world spillage. Then, in the second stage, we use the learned fluid parameters to minimise spillage over spatio-temporal action spaces (angular velocity, relative position) using Bayesian Optimization. We compared 3 deployment strategies: (D1) one-shot pouring –planning using simulation only; (D2) iterative –planning using real execution only; and (D3) planned iterative – planning starting with simulation policy and continuing with real executions only.

Result

We evaluated our approach using a 6-DoF robot (UR10) and a digital weighing scale to measure spillage. Each real pouring execution takes about 90s of which the robot only spends about 2-5s to pour and the simulation ran at 60FPS. The figure below shows the mean spillage per real iteration achieved for each cup across the three deployment methods. We observed that for challenging cups with narrow openings (Cup 2) there is a noticeable advantage of starting with the simulation policy (D3), but for simpler cups as Cup 1, a direct policy from the real world might suffice.





Example of pouring in Cup 3

Impact

Manipulation of liquids using autonomous robots opens doors to a plethora of exciting applications across diverse fields such as medicine, construction and assistive robotics. The exploitation of fast but approximate simulation offers a promising new direction for real-time guidance of adaptable policies in dynamic environments.

Future Work

We are investigating a number of exciting directions such as increased robustness to uncertainty in the dynamic environment. E.g. a person holding the receiving cup. We are also looking to propose a single-step solution, using reinforcement learning, that does not require an explicit training step.

Publications

Tatiana López-Guevara, Nicholas K. Taylor, Michael Gutmann, Subramanian Ramamoorthy, Kartic Subr, Adaptable pouring: Teaching robots not to spill using fast but approximate fluid simulation, Conference on Robot Learning (CoRL), 2017.

Research Area: Interactive robotic inspection strategies using unstructured data

ConvNet-Based Optical Recognition for Engineering Drawings

Supervisor: Dr Theo Lim
PhD student(s): Andrew Brock

Objectives

The incipient generation of smart manufacturing technologies is increasingly data-driven, presenting a unique set of opportunities and challenges. Automatic analysis of raw data such as scanned drawings requires a reliable and precise perception frontend capable of extracting and interpreting salient information on multiple semantic levels. We develop a custom pipeline for analysing 2d engineering part drawings that joins end-to-end learned modules with rule-based heuristics, with an especial focus on recognizing, extracting, and translating unstructured GDT information into data structures for robotic interpretation. We also investigate several relevant fundamental problems in modern machine learning, arriving at unique techniques for accelerating training and improving model design without large-scale compute resources.

Approach

We develop a fully convolutional object detector, inspired by recent developments such as OverFeat and RPNs, and tune our design to handle the drastic differences in object scales and complexity present in engineering drawings. Our system employs a novel parametrically efficient multiscale convolutional block and regularizer to aid with the low-data training regime.
Corrolary to our design, we develop SMASH, a technique for efficiently searching over the vast architectural design space at the cost of a single training run, and FreezeOut, a technique for accelerating training by progressively freezing the lower layers of a feed-forward network.

Result

Our object approach enables classification and localization on a 10-fold cross-validation of an internal dataset for which other techniques prove unsuitable. We successfully recognize the majority of critical objects in our test images, and are able to integrate the detections into our pipeline to enable the beginnings of true drawing interpretation, including part segmentation, arrow regression, and vertex matching. We also validate our MDC blocks and Orthogonal Regularization on common benchmarks, demonstrating improved performance at only minor computational cost.

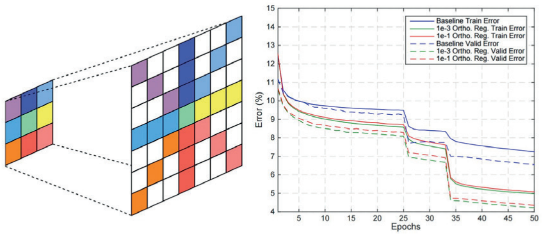


Figure 1: MDC Blocks (left) and training curves with and without orthogonal regularization (right).

We validate our one-Shot Model Architecture Search through Hypernetworks (SMASH) for convolutional networks on CIFAR, Downsampled ImageNet, ModelNet-10, and STL-10. We demonstrate that our efficient metric correlates strongly with true performance, enabling us to explore thousands of architectures without incurring the full cost of training, as in evolutionary or reinforcement-learning-based methods. Our best-found architectures perform competitively with similarly sized hand-designed networks, and achieve a best-reported 38% top-1 error on the recently introduced Imagenet32x32 benchmark.

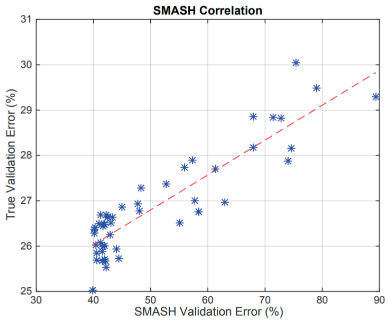


Figure 2: True error and smash validation error for 50 different random architectures on CIFAR-100.

Through experiments on CIFAR, we empirically demonstrate that FreezeOut yields savings of up to 20% wall-clock time during training with 3% loss in accuracy for DenseNets, a 20% speedup without loss of accuracy for ResNets, and no improvement for VGG networks. FreezeOut is easily implemented with around 15 unique lines of code.

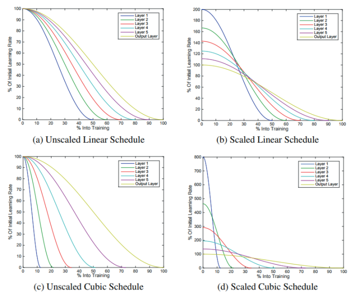


Figure 3: Freezeout Learning Rate Schedules

Future Work

We plan to have a complete proof-of-concept for extracting the 3-dimensional geometry of simple parts and associating features to tolerance callouts. The primary bottlenecks in completing this are completing the key point extraction algorithm, training a higher accuracy object detector, improving line detection, and developing a modular set of logical rules to enable the system to associate callouts with extracted features. From there, we expect to focus on expanding the complexity of the parts the system can deal with by developing more sophisticated geometry extraction, and to make the compute-heavy aspects of the vision frontend suitable for deployment on consumer systems through model compression. With the vision frontend suitably refined, we will move to the inspection planning phase of the project, and look to extend upon the drawing analysis tools in concert with existing CAIP software to generate part inspection plans.

Impact

Our 2016 publications have been cited a total of 56 times in the past year and featured in multiple international news venues.

Brock, A., Lim, T., Ritchie, J. M., & Weston, N. (2016). Neural photo editing with introspective adversarial networks. ICLR Conference 2017. arXiv preprint arXiv:1609.07093.

Brock, A., Lim, T., Ritchie, J. M., & Weston, N. (2016). Generative and discriminative voxel modeling with convolutional neural networks. 3D Deep Learning Workshop at NIPS 2016, Barcelona, Spain. arXiv preprint arXiv:1608.04236.

Brock, A., Lim, T., Ritchie, J. M., & Weston, N. (2017). FreezeOut: Accelerate Training by Progressively Freezing Layers. arXiv preprint arXiv:1706.04983.

Brock, A., Lim, T., Ritchie, J. M., & Weston, N. (2017). SMASH: One-Shot Model Architecture Search through HyperNetworks. arXiv preprint, August 18, 2017.

Brock, A., Lim, T., Ritchie, J. M., & Weston, N. (2016, August). Context-Aware Content Generation for Virtual Environments. In ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (pp. V01BT02A045-V01BT02A045). American Society of Mechanical Engineers.

Brock, A., Lim, T., Ritchie, J. M., & Weston, N. (2017, August). Convnet-based optical recognition for engineering drawings. In ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (IDETC2017-68186). American Society of Mechanical Engineers.

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.

Sharing responsibility
RSSB, UK
This project investigates how the task of driving a train is likely to evolve in the next 10 years, what other changes in rail and related industries are driving this change, how driver selection and training processes will evolve to support this change, how these changes will be received by existing train drivers and operational staff.

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.

Robotic Inspection and Manipulation for Fusion Remote Maintenance
UK Atomic Energy Authority
This PhD project aims to develop new technologies to support operators of RH robotics systems in nuclear facilities. Current RH systems, though reliable and capable, suffer from limitations in visualisation and capabilities of dealing with confined workspaces. The vast majority of tasks are carried out through strict human-in-the-loop operation. Future nuclear remote maintenance systems will require more advanced visualisation capabilities and automation of basic RH/ inspection tasks in order to cut down on maintenance time and increase plant price-performance. This research will complement already-existing RACE research into AR and remote handling task automation for these future applications.

" I'm funded by HRI (Honda Research Institute Germany) at the Edinburgh Centre for Robotics, which provides me with the opportunity to access the environment, the knowledge and the facilities of both organisations. This is of great importance when developing cutting edge research and disseminating it all around Europe"
Theo - Phd Student 2016 cohort

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.

To ensure that the UK is best placed to maximise this opportunity, the Edinburgh Centre for Robotics offers an innovative 4-year PhD programme which aims to equip graduates with the technical skills and industry awareness required to create an innovation pipeline from academic research to global markets.

Although the Centre is principally funded by EPSRC, we aim to augment this each year with a number of industry funded places. This additional funding maximises the number of students who can participate in our cutting-edge programme and in turn provides industry with a wider talent pool of innovation-ready graduates.

How to engage with the Centre

Any company with a research activity in the UK 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 before beginning the research phase at one of the partner universities.

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.

Key features and benefits of engaging with Edinburgh Centre for Robotics

- Access to world leading academic expertise to provide industrial R&D solutions
- Access to world class infrastructure through the recent £6.1m EPSRC capital grant ROBOTARIUM
- Developing graduates into industry leaders of tomorrow through excellent training opportunities, supplemented by training in commercial awareness, social challenges and innovation
- Industry informed training and seminars
- Industry advisory panel providing direction to the Centre's research activity

If you are interested in submitting a proposal for a new research project, please contact:

Professor David Lane d.m.lane@hw.ac.uk
Professor Sethu Vijayakumar sethu.vijayakumar@ed.ac.uk

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.

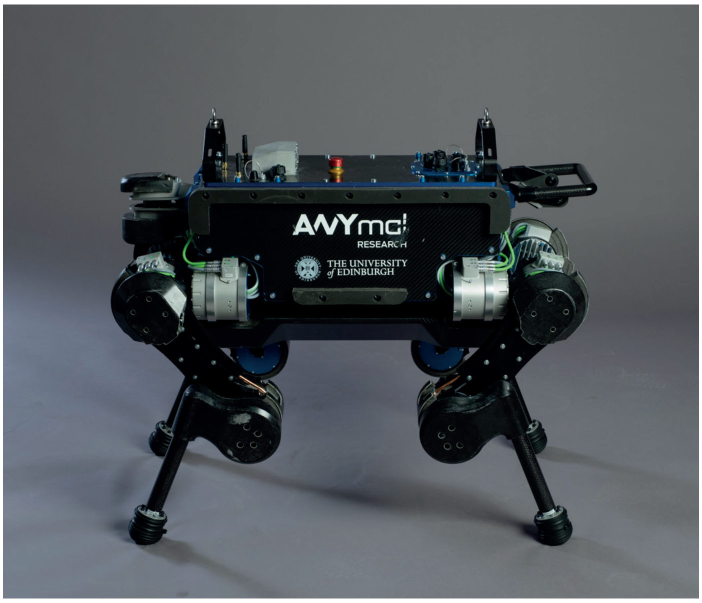
Enabling Facilities, underpinning the above components and comprising rapid prototyping and micro-assembly equipment for fabrication and inexpensive duplication of novel (bioinspired) robot embodiments, their sensors and their on-board computing. Also, state of the art computing accelerators with programmable 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**


FLASH MKII


KUKA
KUKA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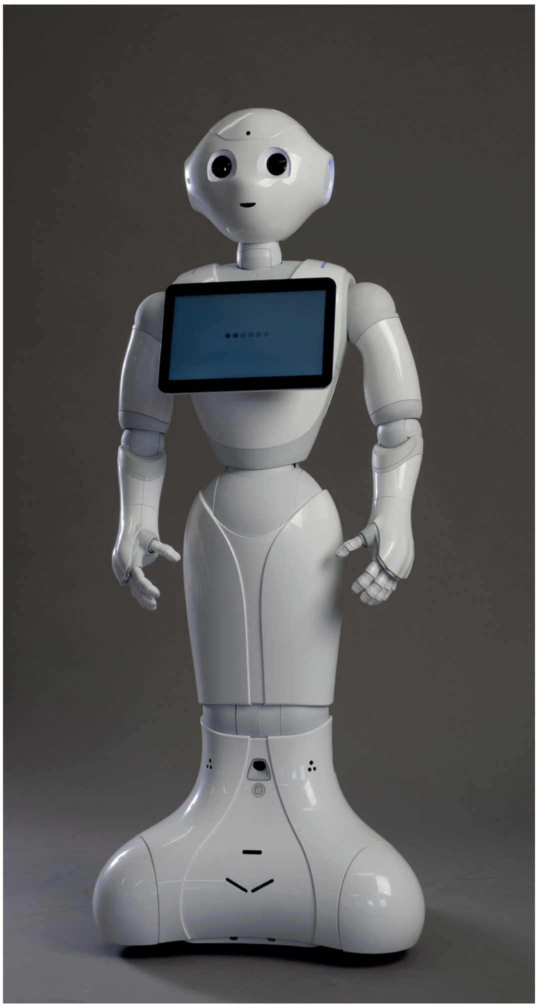



Evo
Logics.de

Highlights 2016-17

2017 – Heriot-Watt University Year of Robotics

2017 was designated Year of Robotics at Heriot-Watt University, providing a great opportunity for the University to showcase its contribution to the development of robotics and artificial intelligence.
The year kicked off with a Design the Year of Robotics Mascot competition which generated huge interest from local primary schools with 1,184 competitors from 41 schools across Edinburgh and the Lothians submitting an entry.
The competition was won by ten-year-old Katy Ashworth from St Margaret's Primary School near Edinburgh who designed 'Watt Bot', a blue humanoid-robot with switches for arms, window-screen wipers for eyebrows and Heriot-Watt University's logo engraved on its chest. Katy's design has been used as the official mascot for the University's Year of Robotics initiative and has been produced using a 3D printer.
A full calendar of activities allowed the University to reach out to schools, the public, academia, industry collaborators, and policy makers. These events included participation in CarFest North and South, a family festival of mix of music, cars and, new for 2017, robots; Guides & Brownies in a Robotic World; The Pint of Science Festival - brilliant scientists come to your local pub to speak about their research and findings; and a series of Robotics & Interaction labs Open Days where the public visited to learn more about our robots.

Katy Ashworth being presented by Professor Oliver Lemon with Year of Robotics Mascot winner certificate

"Pepper and other humanoid robots have learned to act in ways that we would deem socially appropriate, a significant step forward from where we were five to 10 years ago. Today's generation of young people are going to grow-up and work alongside autonomous, intelligent machines in such a way that social robots will become the norm. Demonstrating how this will come about is one of the key aims of the Year of Robotics."

Professor Oliver Lemon - Year of Robotics team

EUROPEAN
ROBOTICS
FORUM
Brought to you by SPARC

European Robotics Forum 2017

After many months of planning it was with a great sense of achievement that we welcomed over 800 delegates to ERF2017 which took place at the Edinburgh International Conference Centre from 22-24 March. This three day conference, featuring seminars, workshops and an exhibition, is the premier European Robotics forum; a meeting place for robotics in Europe, bringing together researchers, engineers, managers, and a growing number of entrepreneurs and business people from all over Europe. The event offers opportunities, through attendance at seminars, to consider the potential of robotics applications for business and societal needs as well as how they might create jobs. The exhibition allows companies and research organisations to demonstrate recent breakthroughs in robotics and their potential business applications.

Delegates received a warm welcome to the forum and to Edinburgh from Dr Bernd Liepert, President of euRobotics and Professor Sethu Vijayakumar, co-Director of the Centre. Keynote speakers included Keith Brown, Cabinet Secretary for the Economy, Jobs and Fair Work; Raia Hadsell, Senior Research Scientist at DeepMind; Stan Boland, founding CEO of FiveAI and Tim Ensor, Chief Commercial Officer at Tharsus.

The theme of this year's forum was Living and Working With Robots and there were 66 individual workshops/seminars of 90 minutes each on this theme. Topics ranged from Robotics for Nuclear Environments, Construction Robotics, Agri-Food, Neurorobotics and Health, generating lots of interesting conversations and opening the door for future research collaborations. Thirty exhibitors took advantage of the exhibition space to showcase their latest robots. This was a great opportunity for the Centre to show off iCub, the latest addition to our humanoid robot family.

Two evening events allowed us to provide some Scottish hospitality to our visitors. A drinks reception for 600 guests was held in the Kingdom of the Scots Gallery in the National Museum with guests having access to view the exhibits in this and the Explore Gallery. We welcomed 500 delegates to the Awards Dinner which was held in the magical Grand Gallery at the museum. Guests were welcomed on arrival by a piper in full regalia who then piped guests upstairs to a Scottish themed dinner. The evening ended on a high note with Beat the Retreat, a colourful display of music and marching. One attendee was inspired to tweet "this truly was a remarkable evening!!"

Highlights 2016-17 (cont)

Student team announced as only UK finalists in $2.5 Million Alexa Prize

A group of PhD students from Heriot-Watt University are the only team from the UK to be chosen as one of three finalists in Amazon's $2.5 Million Alexa Prize. They go forward to the finals along with Czech Technical University and the University of Washington.

Competitors came from 14 other universities including Princeton, Harvard, Berkeley, Edinburgh, and Carnegie-Mellon.

The six strong student group, from the Interaction Lab in the School of Mathematical and Computer Sciences, were originally chosen from over 100 entries from 22 countries world-wide.

The competition focuses on the challenge of building 'A socialbot that can converse coherently and engagingly with humans on popular topics for 20 minutes'.

When short-listing, judges looked at the potential scientific contribution to the field, technical merit of the approach, novelty of the idea, and the team's ability to execute against their plan.

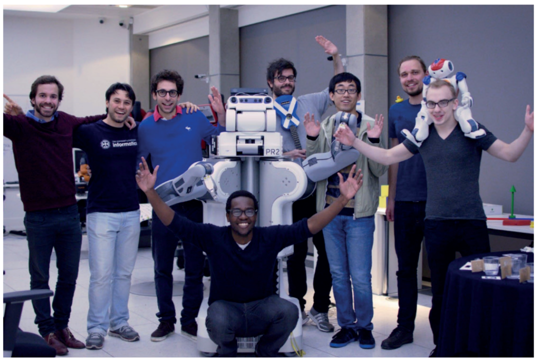
Thousands of Alexa customers conversed with the socialbots on popular topics and their feedback ratings were also used in short-listing for the final.

The Heriot-Watt University team, What's Up Bot, has already received $100,000 stipend, Alexa-enabled devices, free Web Services (AWS) to support their development efforts, and support from the Alexa Skills Kit team.

Winners will be announced in November and the finalist with the highest performing socialbot will win $500,000 with an additional $1 million prize being awarded to the University whose team achieves the grand challenge.

"This is a fantastic result for the hard-working students and staff involved in this prestigious competition. This success further enhances our reputation as one of the leading institutions for research and robotics. It also links in with our current Year of Robotics, celebrating our pioneering research on robotics, artificial intelligence (AI) and human-robot interaction. It also firmly stamps us on the international map for delivering and achieving exceptional higher education."

Professor Richard Williams OBE, Principal and Vice-Chancellor of Heriot-Watt University



University of Edinburgh team

Heriot-Watt University team

"This is a wonderful result for our team which demonstrates that Heriot-Watt University is among the top institutions in the world for research on conversational AI and Natural Language Processing. The challenge provided an amazing experience for our students to be able to learn about Amazon's Alexa services and to create and test their own social chatbot."
Professor Oliver Lemon - School of Mathematical and Computer Sciences, Heriot-Watt University

Heriot-Watt University Alexa team hackathon

"Through the Alexa Challenge, we have also had unique access to large amounts of real customer data and feedback which has helped the team to improve their system. Being part of this challenge has provided our students with invaluable insights and experience in the real-world deployment of a large-scale AI system to real people."
Professor Verena Rieser - School of Mathematical and Computer Sciences, Heriot-Watt University

"It is an amazing experience to take part in this coveted competition and we're all delighted to be have been selected to enter the final. It's been a privilege working with such a great team. I believe that determination, focus and a desire to push the scientific barriers, has helped us get to the finals."
Ioannis Papaioannou - Student Team Leader

Highlights 2016-17 (cont)

VW Challenge

As part of the Centre's research activities a team of PhD students, comprised of Iris Kyranou, Teun Krikke, Boris Mocialov and Ioannis Chalkiadakis, is participating in a Robotics competition organized by the VW:Data Lab and NVIDIA. Supported by Professor Sethu Vijayakumar and under the supervision of Dr. Sen Wang, the students replied to the call for this challenge, and were selected by VW together with another 20 students from universities in Germany, Spain and the Netherlands to participate in a 4-week intensive research challenge in the Data Lab's offices in Munich.

During the challenge participants are required to build a robotic platform to autonomously carry out a manipulation task using state-of-the-art machine learning methods. All teams have been provided with equipment from the VW:Data Lab and NVIDIA, and are constantly evaluated for their innovative solutions to subtasks, their cooperation with other teams, and the presentation of their progress. The team members will build on their extensive and diverse background in robotics to provide novel machine learning-based solutions to common problems in robotics such as object detection, localization and clustering.

The challenge will culminate at the GPU Technology Conference 2017 organized by NVIDIA in Munich on 10-12 October, where the winners will be announced. The challenge and the ECR team's progress can be found at the challenge blog: http://dlrc.pages.argmax.ai/blog/ .

Professor Sethu Vijayakumar invited as speaker at the India-UK Tech Summit - Nov 2016

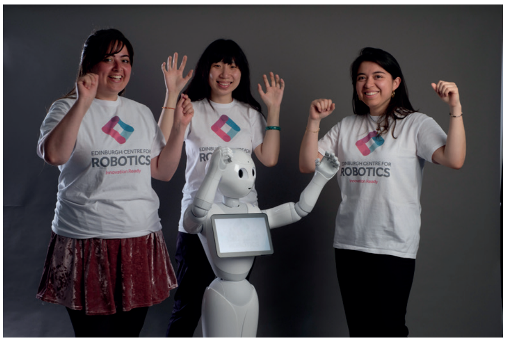
Professor Vijayakumar, ECR Director, was one of the high profile speakers headlining the biggest showcase of UK-India Technology in sectors ranging from Agriculture, Life Science, Healthcare, Smart Cities, Advanced Manufacturing and of course, Robotics held in New Delhi in November 2016. ECR affiliated student, Agamemnon Krasaulis, and enterprise fellow, Sandy Enoch, showcased live demonstrations of their research at the high profile exhibition venue. TECH Summit, supported by the UK Department of International Trade (DIT), India's Department of Science and Technology (DST) and Confederation of Indian Industries (CII), is India's largest knowledge and technology conference and exhibition.
For more information about the event, checkout: http://www.ciitechknow.com

Professor Sethu Vijayakumar discussing robotics with UK PM Theresa May

Pepper makes an appearance on Blue Peter

An inter-disciplinary team, involving students and academics from across Heriot-Watt University, took the CBBC channel by storm on Thursday 10th August with an appearance on the long-running magazine programme, Blue Peter.

The show, which is watched by 6-12-year-olds, was co-hosted by Pepper, one of the University's artificially intelligent social robots and featured an interview with psychologist Dr Thusha Rajendran from the School of Social Sciences as he guided children's presenter Barney through current robotics research.



"There is significant evidence to suggest that young people, especially girls, become disengaged with STEM subjects as early as seven or eight years old. It is therefore vital that universities like Heriot-Watt proactively engage and inspire children about their future career choices as well as helping them to understand what role robotics will play in their daily lives in the near future."

Dr Thusha Rajendran - Reader in Psychology, School of Life Sciences, Heriot-Watt University

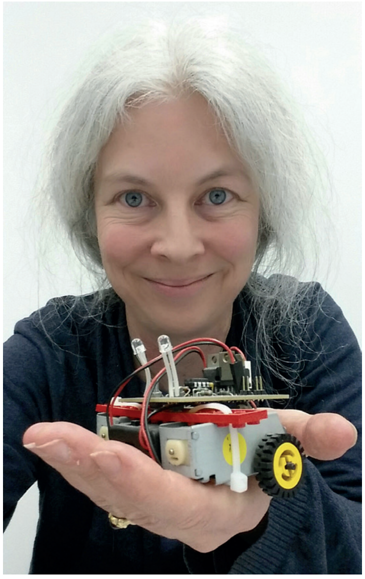
Professor David Lane guest of honour at Policy UK event

Centre Director, Professor David Lane, was guest of honour at Policy UK's event "The Robotics and Artificial Intelligence Future: Putting Britain at the Forefront of the 4th Industrial Revolution". The event was held in London in November 2016 and saw Professor Lane, lead author of the RAS2020 UK Robotics and Autonomous Systems Strategy, speak about "Next Steps for Implementing the Robotics and Automated Systems 2020 Strategy". The event also considered the Science and Technology Committee's enquiry into Robotics and Artificial Intelligence and provided an opportunity for delegates to discuss how government and industry can best enable technologies to fully recognise their economic potential. The forum also looked at the impact of technological changes and how to minimise any negative effects on the population.

Workshop on the era of embedded intelligence

The Centre organised a seminar on the topic of "Embedded Intelligence supporting resilient and sustainable systems, organisations, networks and societies" in August 2017. Professor Michael Pecht from the University of Maryland was the keynote speaker.
The seminar aimed to promote the importance and impact this area is making on society, and to engage the audience on how we innovate and train the next generation of engineers, scientists and business people to prosper in this data driven age.

Highlights 2016-17 (cont)



Robocrab Project
The 'Robocrab' project at the University of Edinburgh, funded by the Australian Research Council, was presented in a paper (joint-authored by a Centre student) at the 2017 'Living Machines' conference at Stanford University.

It describes the first implementation of a crab-inspired robot platform able to move in any direction and with complete 360 degree vision resembling the crab's eye-stalks. The platform was used to imitate the predator avoidance response observed in real fiddler crabs by collaborators at the University of Western Australia.

Assisted Living Lab
A new state-of-the-art laboratory has been added to the Robotarium West in Heriot-Watt University. The facility has been partially funded by the EPSRC UK Robotics and Autonomous Systems Network (UK-RAS Network). It is situated in the Heriot-Watt wing of the Lyell Centre and provides a new 'Assisted Living Lab' where roboticists and computer scientists, usability and health experts, psychologists, and sociologists, can work alongside people with assisted living needs and those supporting them, to co-design and test innovative solutions for healthy ageing and assisted living.
The new laboratory is designed to resemble a typical single level home comprising an open-plan living, dining and kitchen area with a bathroom and bedroom. The laboratory hosts the latest generation of domestic robots and smart home technology.
Research at the new facility will focus on developing robotic and other intelligent and interactive technology able to empower individuals and their support network, looking after the safety and the comfort of their users, assisting them in their daily lives, while also detecting and smoothly adapting to their constantly evolving needs. These features can greatly simplify design and customization of assistive living systems while benefiting from modern technological trends to promote their adoption as part of highly personalised and integrated care practices.

Internet of Robotic Things workshops

Dr Mauro Dragone organised two workshops to investigate the added value and the challenges associated with building integrated IoT and Robotic systems, at the European Robotics Forum 2017 in Edinburgh in March, and at the IoT Week 2017 in Geneva in June respectively,
The events tackle the lack of shared understanding of techniques, methods and value proposition from platforms available across Robotics and IoT, The view discussed at both workshops is of an Internet of Robotic Things (IoRT) as the next evolution of the IoT, which can potentially transform the IoT landscape currently dominated by business models built on simple (passive) devices, moving the IoT a step further toward real integration between the digital and physical world and enabling novel applications and business opportunities in almost every sector where robot assistance and IoT technology can be imagined.

UK RAS White papers

Professor Oliver Lemon and Dr Mauro Dragone contributed to "Robotics in Social Care: A Connected Care Ecosystem for Independent Living".
Collaborating with an esteemed network of leading UK academics, it is a testimony to the expertise and impact the Centre delivers in RAS that we are contributing and shaping the national debate on UK innovation in Robotics and Autonomous Systems.
The white papers were released on the 30th of June as part of the International Robotics showcase http://hamlyn.doc.ic.ac.uk/uk-ras/white-papers

http://hamlyn.doc.ic.ac.uk/roboticsweek2017/events/international-robotics-showcase

ECR Academic Dr Mauro Dragone presents at ScotSoft 2016

Edinburgh Centre for Robotics academic Dr Mauro Dragone spoke at ScotSoft 2016 which took place in October 2016 at the Edinburgh International Conference Centre. The title of his presentation was "From Robotic Ecologies to Internet of Robotic Things: Artificial Intelligence and Software Engineering Issues".
Dr Dragone illustrated the potential of building an Internet of Robotic Things, and discussed the artificial intelligence and software engineering issues associated with its realisation. Building smart spaces combining IoT technology and robotic capabilities is an important and extended challenge for EU R&D&I, and a key enabler for a range of advanced applications, such as home automation, manufacturing, and ambient assisted living (AAL). During his talk, Dr Dragone provided an overview of robotic ecologies, i.e. systems made up of sensors, actuators and (mobile) robots that cooperate to accomplish complex tasks and discussed the Robotic Ecology vision, highlighting how it shares many similarities with the Internet of Things (IoT).

UK Robotics Week
24th -30th June 2017

UK ROBOTICS WEEK 2017

The Centre was very active during UK Robotics week and the following activities give a snapshot of some of the events in which we participated.

19th June 2017

Social Care Robot Challenge
20 participants attended an interactive workshop focused on examining robotic and ICT solutions for healthy ageing and assisted living. The event took place in the newly built "Living Lab" - a space where roboticists and computer scientists, as well as usability and health experts, psychologists, and sociologists, can work alongside people with assisted living needs and those supporting them, to co-design and test innovative solutions for healthy ageing and assisted living.

The workshop included representatives from Innovate UK, healthcare stakeholders from the City of Edinburgh Council (Community Alarm Telecare Service, Community Occupational Therapy Rehabilitation Service), Dumfries & Galloway Health and Social Care Partnership, Social Care Alba, CENSIS (Innovation Centre for Sensor and Imaging Systems), NHS Education for Scotland, NHS Lanarkshire, Stroke Education Lothian and Borders, Stroke Association, LifeCare Edinburgh,as well as experts in cognitive ageing, interaction design and robotics from Heriot-Watt University.

The workshop was part of the UK Social Care Robot Challenge 2017 (http://hamlyn.doc.ic.ac.uk/hsmr/events/social-care-robot-challenge-2017), a nation-wide cooperative venture that aims to encourage investigation into how robots can be integrated in the healthcare services of the future, to help address the predicted rising costs and strain on healthcare provision and services in the UK. The challenge aims to draw out ideas of how robotics can be used for different aspects of our healthcare system, working with and supporting health professionals to provide improved physical and cognitive deficit support.

30th June 2017

Robotics Open Day at Heriot-Watt University

The Open Day at Heriot-Watt University was a great opportunity to showcase some of the work the Centre is doing in the area of social care and assisted living by presenting the iCub, Pepper and Miro robots.

Visitors to the Open Day had the chance to visit the Robotics Lab, the Human Robot Interaction Lab, and the Living Lab. In these labs, the Pepper presented a dialog system and the iCub demonstrated a food preparation task.

After the tour visitors were able to actively engage with the Sphero and virtual reality, and see 3D printing demonstrations. Visitors could also learn about some of our other activities such as the Amazon Alexa challenge.

The Open Day attracted 84 visitors from the general public, including families, school teachers and Heriot-Watt alumni. The audience were actively engaged, asking questions and participating in discussions.

Robotics Open Day at University of Edinburgh

Academics at the University of Edinburgh put on an open day demonstration, which involved the PR2 taking task level instructions from a human user and autonomously carrying out mobile manipulation tasks. These included fetching utensils and fruits from different places, handing over these items to the human (or placing them in a bowl) and then putting away utensils.

Over 130 people of all ages attended the five demonstration sessions. This included primary school children to retirees, and the audience were actively engaged through questions and discussions.

UK ROBOTICS WEEK
2017

If you would like to find out more about UK Robotics Week 2017 and the UK RAS Network please visit:
http://hamlyn.doc.ic.ac.uk/roboticsweek2017

Achievements

Spirit of Heriot-Watt Award: Outward Looking

The ERF2017 Organising Team were awarded the Outward Looking category in the 2017 Spirit of Heriot-Watt Awards. This award recognises the huge amount of effort the team put into organising and delivering the highly successful 2017 European Robotics Forum which reached over 800 delegates from academia and industry.

ERF2017 Organising Team:
Patricia Vargas, David Lane, Katrin Lohan, Anne Murphy, Iain McEwan, Mustafa Suphi Erden, Helen Hastie, Siobhan Duncan, Frank Broz, Mauro Dragone, Christian Dondrup, Alistair McConnell, Azmi Mohd Khairul Hassan, Marta Vallejo, Mei Yii Lim, Lynne Baillie, Robert Goodfellow

Best Paper Awards

Yanchao Yu, Arash Eshghi, and Oliver Lemon were awarded Best Paper for "Learning how to learn: an adaptive dialogue agent for incrementally learning visually grounded word meanings." Proceedings of the First Workshop on Language Grounding for Robotics, pages 10–19, Vancouver, Canada, July 30 - August 4, 2017. c 2017 Association for Computational Linguistics

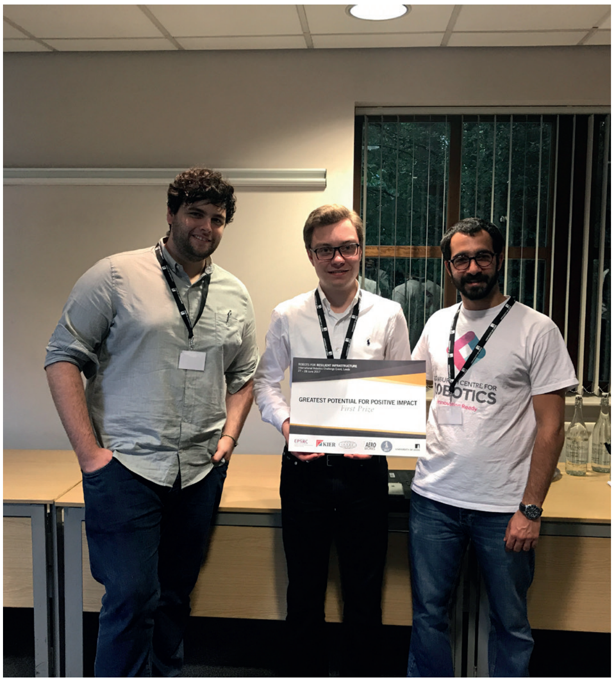
The full paper can be accessed here: http://aclweb.org/anthology/W17-2802

Xavier Herpe, a PhD student supervised by Dr Xianwen Kong and Dr Matt Dunnigan, received a best paper award for his paper entitled "Design, fabrication and testing of a hybrid micro-motion XY Stage driven by voice coil actuators" at the International Conference for Students on Applied Engineering, Newcastle, 20-21 October, 2016. This was Xavier's second best paper in a row. In 2015, he received the Best Student Paper Award at the 2015 IEEE International Conference on Automation and Computing (ICAC 2015) held on September 11-12, 2015 in Glasgow, UK.

Students win 1st prize at Robots for Resilient Infrastructure Competition

A team of students from the Centre was awarded first prize for Greatest Potential for Positive Impact for their work on Robust Shared Autonomy for Mobile Manipulation in Extreme Environments at The Robots for Resilient Infrastructure Competition, an international robotics challenge event which was held at the University of Leeds in June 2017. The students' research allows for shared autonomy operation via limited bandwidth wireless links which empowers the human operator to use a blend of teleoperation, punctuated and full autonomy. The framework reduces operator fatigue by automatically verifying the validity of intended motions and continuously checking the environment for dynamic changes, altering the robot's behaviour along the way to ensure safety in shared workspaces while minimising dis- and interruptions.

The winning team comprised Wolfgang Merkt, Yiming Yang, Theodoros Stouraitis and Christopher Mower who were supported by Professor Sethu Vijayakumar and Dr Maurice Fallon.



Abstract

This work presents a fully integrated system for reliable grasping and manipulation using dense visual mapping, collision-free motion planning, and shared autonomy. The particular motion sequences are composed automatically based on high-level objectives provided by a human operator, with continuous scene monitoring during execution automatically detecting and adapting to dynamic changes of the environment. The system is able to automatically recover from a variety of disturbances and fall back to the operator if stuck or if it cannot otherwise guarantee safety. Furthermore, the operator can take control at any time and then resume autonomous operation. Our system is flexible to be adapted to new robotic systems, and we demonstrate our work on two real-world platforms – fixed and floating base – in shared workspace scenarios. To the best of our knowledge, this work is also the first to employ the inverse Dynamic Reachability Map for real-time, optimized mobile base positioning to maximize workspace manipulability reducing cycle time and increasing planning and autonomy robustness.

This work was accepted to appear at the IEEE Conference for Automation Science and Engineering (CASE) in Xi'an, China in August 2017.

Official Competition Demo:
https://www.youtube.com/watch?v=jU-aAaYzF34&index=3&list=PLWViEDJit8HyK9...

Made In Leeds coverage:
https://www.youtube.com/watch?v=JWtq5_uKyIA&index=4&list=PLWViEDJit8HyK9...

Student Activities

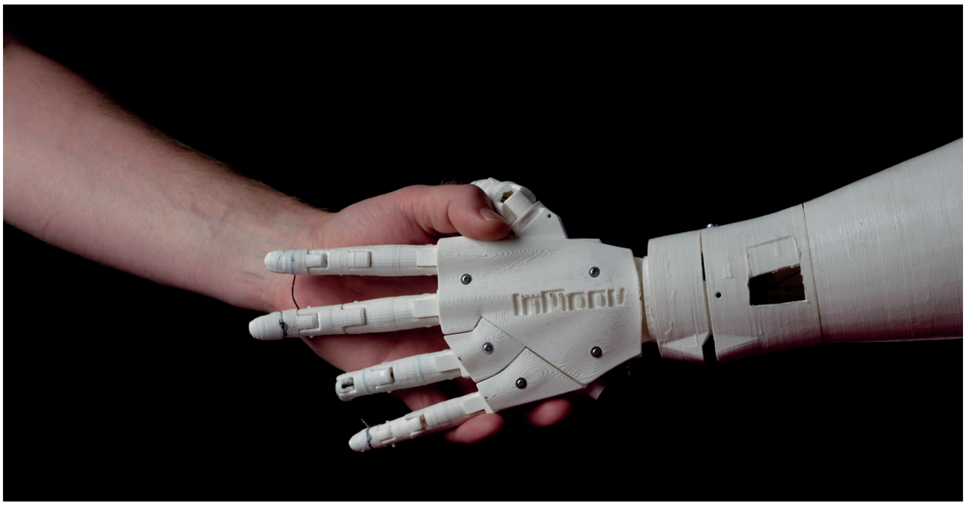
Heriot-Watt University Robotics Society grows to over 150 members

The recently formed Robotics Society at Heriot-Watt University is the next step on a journey that started with the Year of Robotics outreach programme. Students came together with the aim of building a butler humanoid robot which would be used to promote robotics and to educate the general public about robots at various Year of Robotics events across the UK.

The Robotics Society is currently 3D-printing, improving an open source robotic platform, InMoov, and developing a software stack for butler-like behaviours. In addition to this technical focus, the Robotics Society is heavily involved in outreach and demonstrations that they hope will generate new collaborations and ideas while bringing together people with a common interest in all things robotic.

To date, the society has printed a dexterous hand and is now starting work on building a second hand and the head with the aim of having a full humanoid body by the end of the year.

At the last count, the Robotics Society had over 150 members ranging from undergraduate to postgraduate students highlighting the significant interest amongst the student population in robotics.



Heriot-Watt University Robotics Society - Union of automation and interaction

https://www.facebook.com/groups/HWURoboticsSociety

https://twitter.com/hwurobotsociety

YouTube https://www.youtube.com/playlist?list=PLGkkVba61RQqlpCx7IjwGVn0y8x2TRJnG

flickr https://www.flickr.com/groups/hwu-roboticssociety/

E-mail hwuroboticssociety@gmail.com

Student Journal Club

RAS CDT students have set up a Journal Club which meets every two weeks with two speakers presenting a recent paper that they had found interesting. There have been talks from many different areas such as classifying EMG signals, analysis of control schemes and swarms. The journal club has no specific robotic theme, a format which offers opportunities and challenges for the participants. Since the research work of the RAS CDT students is so diverse, the journal club is able to provide a range of learning opportunities 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 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 attending.

The journal club is entering it's fifth month and there has been a healthy turnout for the majority of these meetings; this number is only expected to rise with the arrival of the new cohort. The majority of the attendees have now presented, and those still to do so have been enthusiastic about speaking at future meetings, so finding speakers has never been difficult. The journal club gives the students an invaluable experience as it helps with presenting to a challenging audience, and it broadens the students' academic horizon.

Public Outreach

Edinburgh International Science festival

As well as training the next generation of robotics researchers, the Edinburgh Centre for Robotics has also been inspiring future ones. For the second year, James Garforth, PhD student 2014 cohort, has coordinated a pair of events at the Edinburgh International Science Festival, one of the largest science and technology public engagement events in Europe, on behalf of the Centre.

Staffed by students from the 2016 cohort of the Robotics and Autonomous Systems CDT, 'Robot Lab' saw robots from the Centre given pride of place in the middle of the National Museum of Scotland's Grand Gallery. The cube-stacking and teleoperated Baxter, along with the football playing Naos, all veterans of the Science Festival, were this year joined by Pepper, who conversed with visitors and gave directions around the museum. These demos lasted for 3 days, with over 6000 people visiting the museum during that time.

Our second event this year was delivered in conjunction with recent Edinburgh robotics startup Robotical. Students from the Centre, along with Robotical's founder Sandy Enoch, ran a series of programming workshops where 10 to 14 year olds learned the basics of controlling the Marty robot through the easy to use Scratch programming language.

Both of these events were incredibly well received by members of the public, as well as providing students in the Edinburgh Centre for Robotics with critical science communication experience. With one more year to go on his own PhD, James hopes to make 2018's Science Festival contribution our biggest yet. Watch this space!

BBC Documentary

The MuMMER project has been filming for a BBC documentary series, in a local supermarket, to be screened January 2018.
MuMMER (MultiModal Mall Entertainment Robot) is a four-year, EU-funded project with the overall goal of developing a humanoid robot (based on Softbank's Pepper platform) that can interact autonomously and naturally in the dynamic environments of a public shopping mall, providing an engaging and entertaining experience to the general public.

The Conversation

Dr David Flynn and Dr Valentin Robu had a paper published in the Conversation on "The new industrial revolution: robots are an opportunity, not a threat"

http://theconversation.com/the-new-industrial-revolution-robots-are-an-opportunity-not-a-threat-81792

New Scientist Live Festival in London

ECR Director, Professor Sethu Vijayakumar and co-PI Professor Barbara Webb were recently invited to present at the prestigious New Scientist Live festival in London. Professor Sethu Vijayakumar presented on "Shared autonomy: the future of interactive robotics". Professor Barbara Webb described "How insects inspire robots", in particular, how her group investigates mechanisms in the tiny brains of insects that enable them to perform impressive feats of long range navigation.

Pint of Science

Pint of Science is a non-profit organisation that brings scientists to local pubs to discuss their latest research and findings.
Dr Subramanian Ramamoorthy, and Professor Ruth Aylett discussed whether the robot invasion could be a good thing.
Dr Ramamoorthy spoke of robots slowly learning to work with humans as assistants and his vision of a future in which robots take up roles beside us in daily tasks including helping with repairs or lending a hand to an overworked nurse.
Professor Ruth Aylett discussed her research work towards making robots a useful and helpful part of ordinary human environments, whether that be in the home, the workplace or the school.
Dr Frank Broz presented his thoughts on how studying human-human interaction can help us design more natural human-robot interaction. He also explored whether we can use social robots to help teach people with autism to correctly interpret social behaviour.

Display at National Museum of Scotland

A morphing machine, developed by Dr Xianwen Kong's team with the support from the EPSRC Impact Acceleration Account, was on display in the National Museum of Scotland from the launch of the new Science and Technology galleries in July 2016 until the end of February 2017. The morphing machine is an artefact representation of adaptive robots and manufacturing systems, which Dr Kong's team has been working on. Such robots and manufacturing systems can adapt rapidly to changing demands.

Professor Vijayakumar was the face of 'BBC Scotland Learning Live' at Glasgow Science Centre with Dallas Campbell, talking live to several schools across the UK.
He also delivered the Edinburgh International Science Festival SIEMENS public lecture (April 13) and an invited keynote at the Global Robot Expo (GREX 2017), Madrid (Feb 3).
Directors Lane and Vijayakumar were the keynote speakers at the China-UK Intelligence Robotics Forum July 4-5 in Shanghai, China with wide media coverage.

Collaboration

Assisted Living Workshop

A first workshop at the new assisted living laboratory in the Lyell Centre took place on the 19th of June, as part of the Social Care Robot Challenge 2017, ahead of the UK robotics week , to examine and discuss robotic and ICT solutions for healthy ageing and assisted living. Attendees included representatives from Innovate UK, and healthcare stakeholders from the City of Edinburgh Council, Dumfries & Galloway Health and Social Care Partnership, Social Care Alba, CENSIS, NHS Education for Scotland, NHS Lanarkshire, Stroke Education Lothian and Borders, Stroke Association Scotland, LifeCare Edinburgh. The workshop was also joined by experts in cognitive ageing, interaction design and robotics from Heriot-Watt University.

COMAC (Commercial Aircraft China)

Professor Vijayakumar has led initiatives that resulted in new collaboration partnerships with COMAC (Commercial Aircraft China) that are funding multiple collaborative manufacturing and asset inspection projects at Edinburgh.

Memorandum of Understanding with RIKEN research Centre

Professor Vijayakumar has also signed an MoU for exchange of researchers and PhD student interns between ECR and the newest branch of the RIKEN research centre, Japan (celebrating its centenary this year) in Tokyo in the domain of AI and machine learning.

Volkswagen AI Laboratories

The Centre has new collaboration partnerships with the Volkswagen AI labs, including some of the CDT students taking part in the Deep Learning for Robotics one month residential challenge in Munich.

The Scottish Informatics and Computer Science Alliance 2016-2018

Dr Subramanian Ramamoorthy and Dr Katrin Lohan are the Research Theme Leaders for Cyber-Physical Systems.

Dr Subramanian Ramamoorthy is also VP - Prediction and Motion Planning in start-up company FiveAI.

International Workshop on Robotics, Sao Paulo, Brazil

Researchers, end users and technology developers attended the International Workshop on Robotics (IWR 2017) which took place on 30th and 31st March at the University of Campinas (Unicamp), São Paulo, Brazil.

This workshop, with a theme of "Robotics and automation: uncovering recent developments and applications on energy, industry, environment, agriculture, health and social settings" was organised jointly by Dr Patricia Vargas from Edinburgh Centre for Robotics and Professor Ely Carneiro de Paiva, from the Faculty of Mechanical Engineering at Unicamp.
IWR 2017 was an excellent opportunity for attendees to network with fellow roboticists and a world-class audience from universities, research institutions and industry. Speakers at the opening session of the workshop included Luis Augusto Barbosa Cortes, Executive Vice President of International Relations at Unicamp; Eulides de Mesquita Neto, of Fapesp; and Ely Paiva.

Patricia A. Vargas explained how developing robotics technology has many applications. For example, her research with Gabriela Castellano, from the Physics Institute at Unicamp, and other colleagues at USP and in the UK involves developing a device that will improve the rehabilitation of hand movements for people who have suffered a stroke.
Professor David Lane, Director of the Edinburgh Centre for Robotics, attended as a special guest and spoke with Professor Milton Mori, from the Unicamp Innovation Agency about innovations within the UK energy industry.

IWR 2017, part of the SAS-ROGE project for developing cooperative swarm robotics, also reflected on the growth in robotics research not only in Brazil but globally, and considered how new collaborative research opportunities might be stimulated, in particular between Scotland and Brazil. Heriot-Watt University and Unicamp have been working together since 2014 to develop new technology as part of a collaboration agreement with São Paulo State Foundation for Support Research (FAPESP-SPRINT calls). However, Dr Vargas believes that the versatility of robotics and how it can be adapted to benefit a number of sectors, including energy, industry, environment, agriculture, health and social care, will open up further opportunities for collaboration.

"Fortunately funding agencies are looking for more research to be carried out that will have real impact in society. As a result of this, we are working towards creating robotics applications that will enable real changes in peoples' lives through adoption of this technology".

Dr Patricia A. Vargas - Founder Director of the Robotics Laboratory, Heriot-Watt University

New Research Programmes

LUCINE - Learning User preferenCes by INtEraction (DataLab - Collaborative Innovation project with EmoTech)
The Interaction Lab at Heriot-Watt University (HWU) and Emotech LTD collaborate on designing and implementing a conversational interface for Olly the Robot, referred to as "Olly" hereafter. Olly is a product developed by Emotech Ltd, an in-home robot with conversational capabilities.
The project utilises the latest techniques in ML, NLP, high-performance computing and human-robot interaction to further develop an integral user experience for the product. The project runs in two phases: While the first stage mostly relied on technology transfer and deployment of existing solutions, the next stage involves a collaborative research effort: Olly will be the first of a kind, which actively learns about user preferences by interaction.
The Olly robot recently won 4 awards for Innovation at the CES showcase including: Smart Home, Drones & Unmanned Systems, Home Appliances and Home Audio-Video Accessories. The CES Innovation Awards is an annual competition honouring outstanding design and engineering in consumer technology products.

MIRIAM (Multimodal Intelligent inteRactIon for Autonomous systeMs)
Dstl Defence and Security Accelerator: This project allows autonomous, unmanned systems to communicate with humans in natural language through a chat interface. This novel communication framework aids better understanding of how missions are being executed, thus increasing transparency of actions and reasoning. It also provides an intuitive mechanism to enable collaborative teaming between humans and machine. This project is in collaboration with SeeByte Ltd and Tekever.

Intelligent iNteraCtion for Autonomy (INCA)
RAEng/Leverhulme fellowship: Professor Hastie's fellowship focuses on Intelligent iNteraCtion for Autonomy (INCA). She will research key issues in communicating with autonomous systems focusing on trust and data overload of operators. Natural language generation techniques will be investigated to capture uncertainty in a manner that conveys the appropriate level of trust for the given situation and the effect this has on the mental model of the user.

Xerox University Affairs Committee (UAC) Award
The focus of this research activity will be to develop methods for learning generative models of complex, unstructured environments with a view to enabling flexible planning using these models. In particular, we will investigate methods that work with weak supervision and a sparse set of reinforcement signals (e.g. feedback from human experts) in order to reduce the cost and effort of building machine learning models.

COGLE (DARPA) - Common Ground Learning and Explanation
Project COGLE is funded by the US agency, DARPA, as part of the recently launched Explainable AI (XAI) programme. XAI centres on machine learning and human/computer interaction, and seeks to create a suite of machine learning techniques that produce explainable models that, when combined with explanation techniques, enable end users to understand, trust, and manage the emerging generation of artificial intelligence (AI) systems. Within this programme, COGLE will be initially developed using an autonomous Unmanned Aircraft System (UAS) test bed that uses reinforcement learning (RL) to improve its performance. COGLE will support user sensemaking of autonomous system decisions, enable users to understand autonomous system strengths and weaknesses, convey an understanding of the system strengths and weaknesses, convey an understanding of how the system will behave in the future, and provide ways for the user to improve the UAS's performance. The work at University of Edinburgh will develop novel methods for hierarchical reinforcement learning as well as new techniques for program induction and compositional model building which will enable us to go back and forth between relatively opaque distributed representations and symbolic representations that are much more amenable to interpretability and human analysis.

Autonomous mapping of airborne & localised contamination (DSTL)
The project objective is to assess a UAV-mounted Fourier-transform spectrometer for broadband detection of explosive gases, and potentially the inspection of surface contamination. This project addresses the specific challenges of contamination mapping, but also potentially to refining scene assessment with high-resolution spectroscopic data. Using autonomous flight algorithms we aim to obtain directly from the closed-loop control signals the wind speed needed for downstream modelling. Hill-climbing algorithms using spatial concentration gradients and Gaussian Process models will be investigated for flying the UAV to the site of maximum contamination.

EPSRC SoCoRo: Socially Competent Robots, Nov 2016-April 2020.
Led by Heriot-Watt University, this project with University of Glasgow as a partner, this project uses the ROBOTARIUM Flash robot and investigates the development of a robot trainer for high-functioning adults with an ASD that can help improve their ability to recognise social signals in the workplace context. It will implement Behaviour Skills Training, a helpful approach that is not widely used as a result of the amount of human input required making it very expensive. The target group suffer from very high levels of unemployment and this work is seen as a step towards changing this.

BBSRC: Visual navigation in ants: from visual ecology to brain
This collaboration with the University of Sussex will develop a novel virtual reality system to test ant navigation capabilities, coupled with brain lesioning studies, to develop a comprehensive model of the visual input, pre-processing, encoding, storage, recovery and use of visual scenes for navigation in ants. Implementation on our 'antbot' robot - which is basically a mobile phone on wheels - will allow us to test the effectiveness of these methods for robust way-finding.

New Research Programmes (cont)

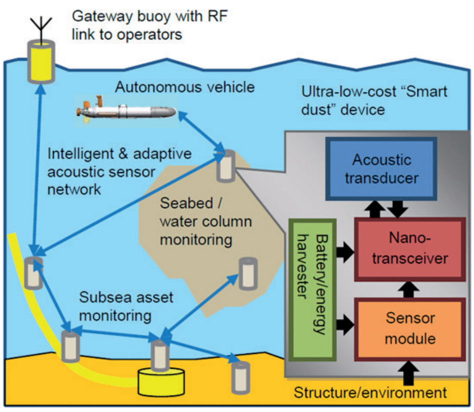
EUMarineRobots (EUMR) 2017-20

This project proposes an access-infrastructure for the deployment of a full-range of aerial, surface and sub-surface marine robotic assets, the combined value of which is far greater than the sum of their parts. EUMR will open transnational access to significant national marine robotics R&D assets across Europe. The EUMR consortium comprises 15 partners from 10 countries who, collectively, can deploy a comprehensive portfolio of marine robotic assets with required associated support assets and expertise. The network is a strong and balanced grouping of globally distinguished key players with a diverse, track-record of excellence across marine / robotic sectors. Partners are members of a wide variety of existing networks, and research infrastructure collaborations both formal and informal across Europe and the world. EUMR is a first stage in aggregating these networks and assets as world-leading for support and growth of a strong community of practice in marine robotics and marine.

EU H2020 Integrating and opening research infrastructures of European interest 2017-2020: Proposal number: 731103-2: Euro 4998736,75 (HWU: Euro 279509,25)

USMART: smart dust for large scale underwater wireless sensing

The aim of this project is to create a smart underwater sensing framework based on ultra-low-cost wireless communication and sensing nodes ('smart dust'). Pilot studies at Newcastle University have demonstrated the feasibility of producing underwater acoustic communication devices known as "nanomodems" (pictured) which use novel, sparse signal processing approaches to vastly reduce hardware complexity, size and cost. These have a manufacturing cost as low as £50, receiver power consumption less than 10mW and tiny dimensions but achieve data transfer and positioning capabilities, up to 2km range, found in much more expensive devices. This base technology will be expanded by investigating new modulation schemes to maximise communication efficiency and low cost sensor modules will be developed, along with flexible interfaces for commercial sensors, to create mass deployable wireless sensor nodes. These will be combined with energy efficient multiple access network protocols based on knowledge of the underwater channel (University of York) and intelligent, sparse sensing/localisation algorithms (Heriot Watt University). This will deliver resilient underwater acoustic sensor networks (UASN) for persistent monitoring with high spatio-temporal sampling rate and near real time data delivery.



HOME Offshore

The goal of the HOME-Offshore project is to deliver the underpinning research required for a fusion prognostic platform for offshore wind farm condition monitoring, operation and maintenance. This will ultimately allow industry to develop improved solutions, significantly above and beyond the current approach. The new approach will treat the wind farm as a unit, allow automation and robotic condition monitoring and system models to predict how operation and behaviour throughout the windfarm affect the life and required maintenance of all system components. This is in stark contrast to the present case where each component is essentially treated as an individual unit, dealt with in isolation, requiring costly, time-consuming and potentially hazardous manual intervention to manage.

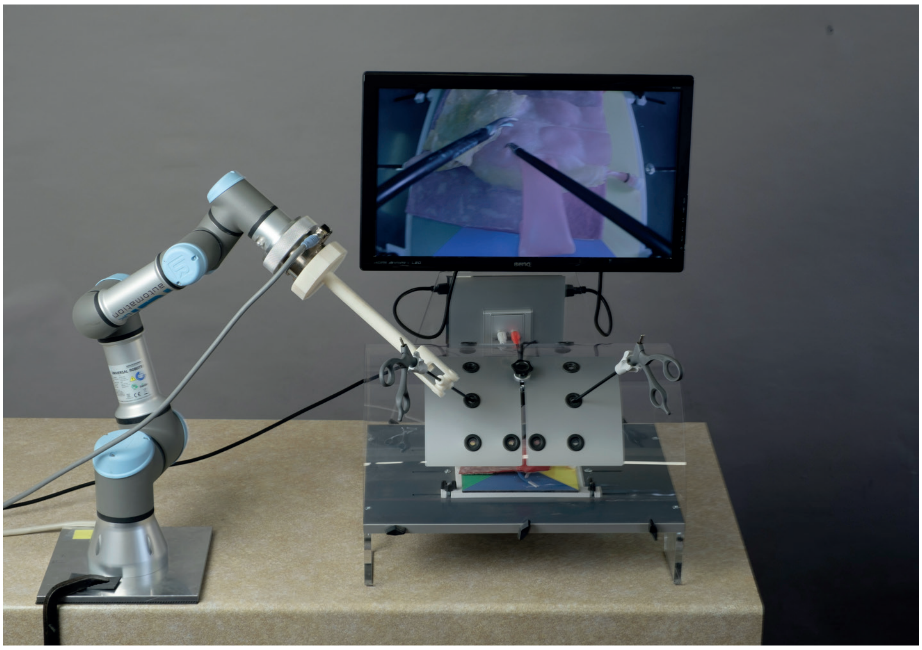
The grant builds on existing world-leading research from several universities in an interdisciplinary approach under one holistic condition monitoring and diagnostic framework for offshore windfarms and connection to shore. This will consolidate advanced modelling techniques from several areas and investigate new methodologies for multi-physics domain modelling of offshore windfarm behaviour and aging. The application of advanced sensing methodologies and the use of robotics to improve present, relatively basic methods will also be assessed. The project will allow existing cutting-edge research to be applied to the more challenging offshore environment. It will allow cross-linkages between existing research to be exploited, facilitating new techniques beyond the present state-of-the-art, in a way impossible with concurrent existing grants.

Specific objectives include:
1. Investigation of methodologies to formulate a multi-physics domain modelling platform incorporating electrical, mechanical (drive train and wind turbine), thermal, aging and stochastics wear effects.
2. Invention and creation of appropriate robotics platforms to assess offshore substations in the hazardous environments outside platforms (e.g. around wind-turbines), subsea (e.g. along cables) and in strong electrical and magnetic fields (e.g. in high voltage offshore substations).
3. Investigation of novel knowledge-driven and data-driven analysis method to diagnose fault signatures and predict incipient faults.
4. Creation of advanced sensing methodologies for use in offshore wind-farm environments. This research will target areas which most affect energy availability, either because of frequency of faults (the power electronic converters and control) or because of the significant down-time resulting from a fault (the turbine drive train and the subsea cabling system).
5. The project's solution will be demonstrated to the public and broadcast media in a flagship publicity event in Salford Quays Manchester, where all aspects of the project will be demonstrated.

EPSRC EP/P009743/1 £3,048,221 (HWU: £468,659.00 FEC) 2017-2020

New Research Programmes (cont)

UnLAPSkill: Understanding Laparoscopic Skills for Robotic Training and Assistance
This EPSRC funded project develops a co-manipulated robotic training and assistance system for conventional Minimally Invasive Surgery (MIS) through performing human-movement analyses. In contrast to virtual reality trainers and tele-operated surgery robots, a co-manipulated robotic system has the advantage that the natural haptic feedback is preserved. In this project we aim to understand how the hand and arm are used during conventional MIS. Hand-impedance and arm-muscle activity measurements are required to develop the quantitative knowledge of skilled manipulation. This knowledge can be used to build a framework that links arm muscle activation to hand-impedance control for fine force and position contact at the hand. Such a framework could offer insights in training level of surgeons and help support the lack of skilled personnel. The goal in this project is to identify the MIS skills based on tool-position tracking, to perform hand-impedance measurements during the complex hand-manipulations, to develop a co-manipulated robotic trainer for MIS where the subject gets real-time feedback and assessment.



MEMMO

Professor Vijayakumar is the PI on the newly awarded EU H2020 proposal MEMMO that aims to enable optimal motion planning for high dimensional robotic platforms using fast pre-computations, with application domains ranging from collaborative construction for aircraft manufacturing and maintenance, exoskeletons for stroke rehabilitation and multi-contact navigation for the mapping and inspection in the construction industry with several of our CDT industrial supporters like Costain involved in the new project.

TrimBot2020

The overall goal of the TrimBot2020 project is to develop and evaluate the technology needed by an autonomous hedge trimmer. It addresses 2 core issues:
1) advancing outdoor robotic technology: low cost robot vehicles for interacting with the natural environment and reliable 3D sensing for robot localisation and scene understanding, and
2) demonstration of a hedge and rose cutting prototype, for potential economic exploitation.
The project will develop and demonstrate novel robotic end effectors for garden trimming, a low cost mobile platform for deploying the end effectors, and reliable outdoor 3D sensing for robot navigation, object and scene structure recognition, and trimming control.
TrimBot2020 is an EC funded 8 partner consortium project with University of Edinburgh as the project coordinator.
The current state is a prototype vehicle with 10 cameras (5 stereo pairs), but which does not yet have the arm and end effector cutters mounted.

Figure 1: Moving vehicle

Figure 2: Garden Semantic Segmentation

New Research Programmes (cont)

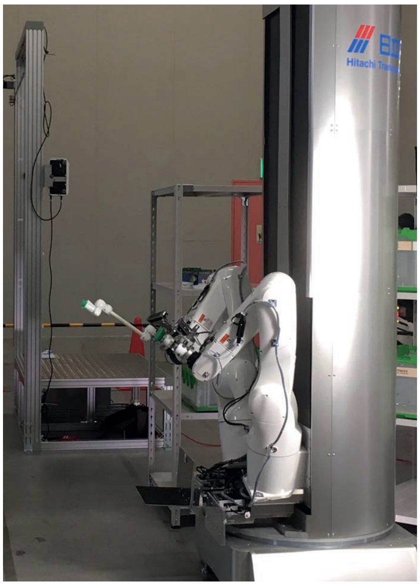
Smart Robots for Intelligent Warehousing: from Research to Translation
Researchers from the Statistical Machine Learning and Motor Control Group have received a boost in funding from various sources to further their study on novel solutions for automated supermarkets and warehouses. Three grants awarded to the group will support work to tackle challenges in dynamic motion planning in pick and place tasks in such cluttered environments.

SLMC scientists led by Professor Sethu Vijayakumar have produced world-leading solutions to these challenges through the release of the Exotica Planning software and the inverse Dynamic Reachability Map based plan representations and adaptation control algorithms - the same technology that is used on the NASA Valkyrie project. The following projects look at expanding this research as well as translating some of these solutions to real world applications in warehousing, robot co-working and factories.

The group received funding of £119,000 for the DST-UKIERI joint project with IIT-Kanpur, India titled 'Learning Robotic Motor Skills, Visual Control and Perception for Warehouse Automation'. This is a three year project, running from April 2017, for core research into improving robustness of warehousing solutions with one of leading research institutions in India.

Professor Vijayakumar will also be working with industrial partners DFKI Germany, COMAU-Italy, Frauenhofer, CRF and Fortiss, to research technologies for pilot deployment in automated supermarkets. This one-year project which started in January 2017 is entitled 'iLEVATOR: intraLogistics Enabled by autonomous Vehicles cooperATing with Operators and Robots' and is funded by EiT Digital.

The group has just completed a second phase of the Hitachi funded translation project on 'Motion Planning for Intelligent Warehousing Solutions', deploying the Edinburgh Exotica Motion planning library in realistic warehouse testing on the outskirts of Tokyo. Plans are in progress to start the third phase of the project.



A new collaboration agreement under the auspices of the British High Commission in Tokyo was signed by the University of Edinburgh and the newly established RIKEN Centre for Advanced Intelligence Project (AIP) that will also help progress research in the area. RIKEN is a premier Japanese Research and Development Centre that celebrates its centenary this year. The agreement will help facilitate cooperation in the fields of machine learning and robotics research, through exchange of interns and visiting faculty.

Medical 'Support' Robot

Using equipment funded by a recent EPSRC award, the research team under supervision of Professor Bob Fisher is starting to explore the possibilities of a medical 'support' robot.
Figure 1 shows a view of the workcell, which is based around a Universal Robots UR10 robot mounted in an inverted position.
Sensing uses 4 Kinect and 4 webcam sensors placed at the edges of the workcell. Additionally, there is a webcam mounted on the robot arm, which is planned for upgrading to a real-time stereo sensor.

Preliminary explorations of the workcell were made through 4 student projects:
1) Locating and recognising medical tools in the workcell (Hanz Cuevas Velasquez); See Figure 2

2) Human-robot interaction using hand gestures (Nanbo Li); See Figure 3

3) Tracking people and arms (Antonio Verdone Sanchez)
See: https://www.youtube.com/watch?v=RZFBXTjE8lk for the intensity and depth images from the 4 Kinects (left) and fitted body model to the moving person (right)

4) Maintaining a good view of the target area with dynamic occlusions (Christos Maniatis).
See: https://www.youtube.com/watch?v=xRm4ZI89Agk (left) 4 camera fused top view, (top right) rendered view from the perspective of camera on arm, (bottom right) occlusion analysis showing pink occluded viewpoints, blue clear viewpoints and red camera position selection.

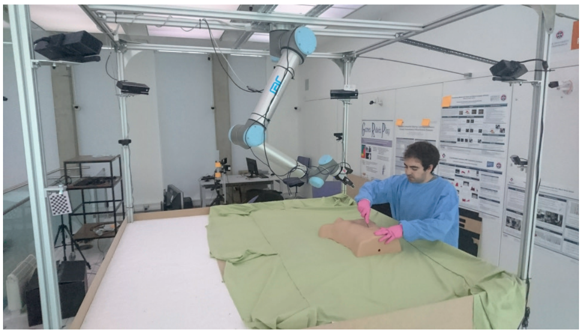


Figure 1

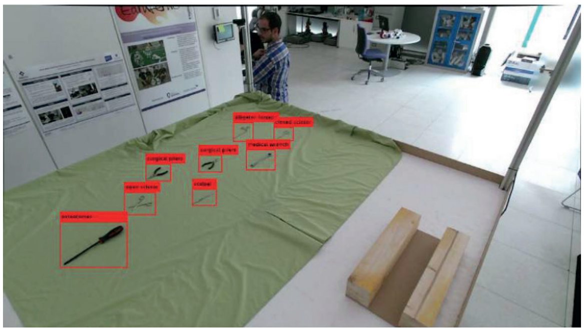


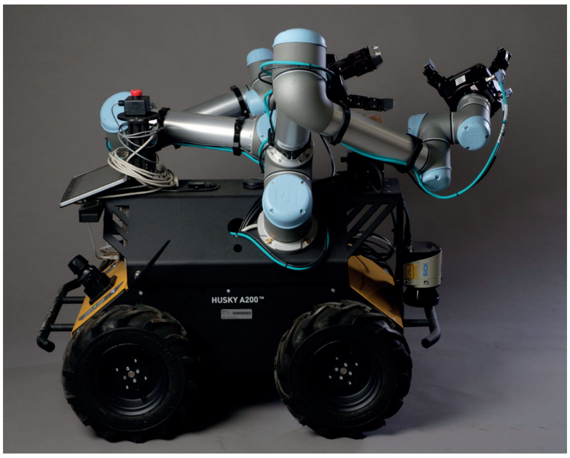
Figure 2

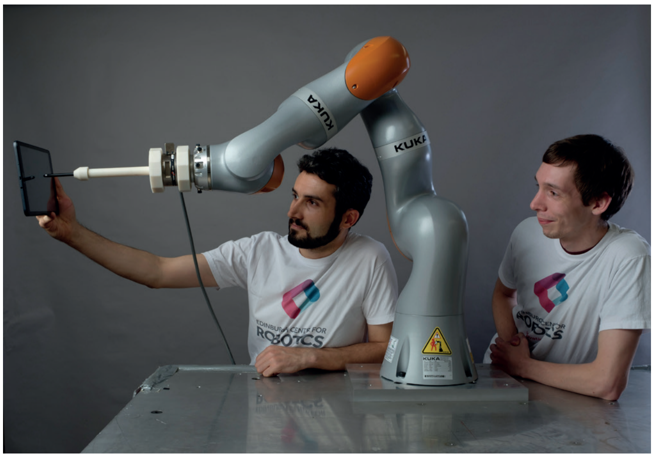
Figure 3

EPSRC
Engineering and Physical Sciences
Research Council

Capital Equipment Award £1M

- Mobile Robot Manipulator; Robotnik Automation S.L.L, Spain
- Husky Mobile robot with 2 UR5 arms; Clearpath Robotics
- Kuka LBR iiwa 14 R820; KUKA Robotics UK Ltd
- Nao Humanoid; Softbank Robotics
- Loxone Smarthome Networking; Loxone UK Ltd
- UR-CB3 Universal Robot 6 axis robotic arm and controller; RARUK Automation Ltd
- DIJ Phantom Quadcopters
- House Living Lab
- ANYmal Quadruped; ANYbotics, ETH Zurich
- GPU (3 x Digits Devbox)
- Lightfield Camera; Raytrix GmbH
- Epson C8XL; Epson
- Zimmer GEP5010N; Zimmer
- Kinect 2 + interface
- Gantry
- PC with GPU, HP, NVidia
- Directional Audio Sensing
- Meta 2 Development Kit; Meta
- Ultimaker 2 Extended + 3D Printer with filaments; Ultimaker
- Force/Torque Sensor; Optoforce





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