EDINBURGH CENTRE FOR

ROBOTICS

Innovation Ready

Annual Review 2015/2016

HERIOT WATT UNIVERSITY

THE UNIVERSITY of EDINBURGH

EPSRC
Engineering and Physical Sciences Research Council

Contents

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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.

NASA Valkyrie Robot
Valkyrie, one of the most advanced humanoid robots in the world, was constructed by NASA-JSC in 2015 and delivered to Edinburgh Centre for Robotics in spring 2016. Weighing 125 kg and standing 1.8m tall, Valkyrie will enable breakthroughs in humanoid control, motion planning and perception.

Image courtesy of NASA

Foreword

Welcome to our annual review highlighting key aspects and activities of staff and students in the Edinburgh Centre for Robotics during 2015/2016; our second year of operation as an EPSRC Centre for Doctoral Training in Robotics and Autonomous Systems (RAS).

At the start of the third year of our programme, we are pleased to report that we now have 43 full-time PhD students engaged in the four-year PhD. There are a similar number of affiliated students working on related PhD programmes or various local or international Masters. Eight of our industrial supporters are now providing full financial support to studentships, augmenting those of EPSRC.

The majority of the ROBOTARIUM equipment is now up and running. Work on many of the platforms (outdoor mapping Husky, the NASA Valkyrie, autonomous marine platforms) has already borne fruit in terms of world leading publications and new industrial collaborations besides H2020 funded projects.

The University of Edinburgh is funding the construction of a new £45m 'Bayes Centre' connected to the Informatics Forum, two floors of which will house new robotics facilities. Work has started on development of the ROBOTARIUM Centre at Heriot-Watt on two floors of the Mountbatten Building and the new £17m Lyell Centre has opened.

We have welcomed 6 new academic appointments to the Centre, Dr Mauro Dragone, Dr Zhibin Li, Dr Ron Petrick, Dr Michael Lones, Dr Timothy Hospedales and Dr Michael Mistry, further strengthening our expertise in human-robot interaction, multi-agent systems, humanoid robotics and automated planning.

A member of the academic team is currently Visiting Professor at Stanford University where, among other activities, he has delivered an AI Distinguished Speaker Series at Stanford. Directors and Centre staff have represented the UK-RAS community on official UK Government scientific missions to China, Japan, USA and Brazil.

We were delighted to welcome Professor Peter Corke (QUT) and Professor Darwin Caldwell (IIT) as keynote speakers at our first annual conference in October 2015. Their informative presentations on "Why Robots See?" and "Humanoid and Quadrupedal Robots" were well received by an audience comprising academia and industry. In addition, staff and students enjoyed presentations from leading international roboticists including Dr Robert Ambrose (NASA), Professor Michael Beetz (University of Bremen), Dr Michael Gienger (HRI-Europe), Professor Marcia O'Malley (RICE), Professor Patrick van der Smagt (TU Munich), and Professor Shou Li, Shenyang Institute of Automation, Chinese Academy of Sciences.

We have continued to build upon the success of our Gateway events during the first year of operation with a wide range of presentations for our students from academics from within and outwith the Centre. A visit to local company SeeByte to view the facilities and to hear a presentation was particularly well received. Students participated in a Humanoid Robotics Sandpit working with teams from LAAS, Toulouse, the University of Birmingham and Kings College, London. Bespoke training programmes in Internships & Career Planning, IP and presentation skills have been offered to students, the latter proving beneficial as they start to increase their involvement in outreach activities.

The arrival of the NASA Valkyrie Robot attracted significant attention from national and local media with a number of press and on-line articles being published. BBC journalists and crew visited the Centre to report on Valkyrie for a special BBC News feature. Students and staff participated in BBC Micro:bit, a live session where they discussed and illustrated the world of robotics. This media attention culminated in Centre Director, Professor Sethu Vijayakumar sitting on the judging panel for the 2016 BBC Robot Wars.

The profile of the Centre has increased significantly in the last 12 months as a result of its involvement in a number of high-level outreach events. These include delivering the IMarEST Lord Kelvin Lecture at Lloyd's Register Foundation, co-hosting a public debate with the British Science Association, and a demonstration of the Centre's research activities at a Scottish Government reception celebrating 'Scotland's Science - Past, Present and Future'. Students led on the organisation and running of a highly successful Robot Lab at the Edinburgh International Science Festival, supplemented by public lectures from students and staff. The Centre also participated in a 3D Printing Open Afternoon at an event to mark the Fifth Session of the Scottish Parliament. Professor David Lane was invited by the British Consulate General, Boston and UKTI to a series of panel sessions with UK roboticists and leaders from the New England robotics community. He also entered into discussions on RAS with the Cabinet Secretary and heads of Westminster government departments in Cabinet Office, participated in a Times Round Table on Disruptive Technology and has given presentations with his co-Director to the Royal Society and the Society of Petroleum Engineers.

We hope the above overview gives you a flavour of what has been happening at the Edinburgh Centre for Robotics over the course of the last year. During the new academic year, we will be launching our new and refurbished ROBOTARIUM facilities, hosting the European Robotics Forum 2017, building on our research activities, extending our outreach activities and much more. We invite you to keep up-to-date with latest developments by subscribing to our bi-monthly newsletter and visiting our website edinburgh-robotics.org

Professor David Lane
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Director
Heriot-Watt University

Professor Sethu Vijayakumar
Edinburgh Centre for Robotics
Director
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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 over 30 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 £7.2m national capital equipment facility.

The Centre includes affiliated students engaged in related EU, ESPRC 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. Next year we will welcome also students from the NERC/ ESPRC 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 the arrival of the NASA Valkyrie robot.

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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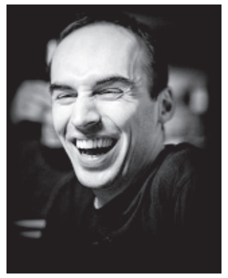

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EPSRC Centre for Doctoral Training

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.

"A community has built up around the RAS-CDT – every student knows what all the others are doing, where they are, and we discuss re-search, any issues and organise social events."
Emmanuel – Ph.D. Student, 2014 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 £7.2m 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).

"Being a partnership between two Universities with large experience in Robotics, the Edinburgh Centre for Robotics gives the student access to a wider range of equipments, facilities, and experts in the field. This environment of collaboration makes it easier to share and discuss ideas, research problems, approaches, opinions, and solutions"
João – PhD student, 2015 cohort

"I really like the wide variety of opportunities both universities offer. During this year, I have attended seminars, courses, talks, events at both universities, being able to get an idea of what other researchers are doing, benefiting from other experiences that are not completely related to my research"
Jose – PhD Student, 2014 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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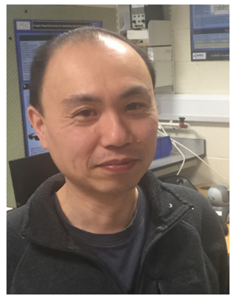

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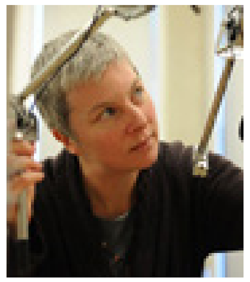

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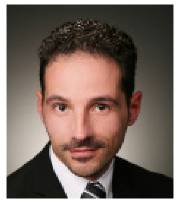
Our students

2014 cohort



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Algorithms for humanoid manipulation combining sample based planning and trajectory optimization

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Monocular SLAM for UAVs in Natural Environments

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Modelling of a human/ exoskeleton system

Emmanuel Kahembwe
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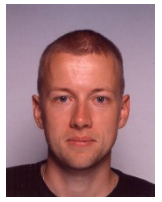
Hierarchical prediction and planning for Human-Robot Interaction



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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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Robust Optimal Control for Humanoid Robots/Model-Predictive Control

Jose Part
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Development of a Cognitive Framework for Knowledge Acquisition and Grounding from Situated Interactive Dialogue in Unstructured Environments

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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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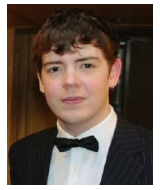
Detection and Tracking of Subsea Pipelines from an AUV



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Robust Sensory Interfaces for Advanced Prosthetics

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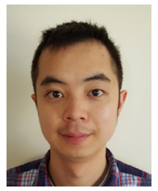
Neural Photo Editing with Introspective Adversarial Networks



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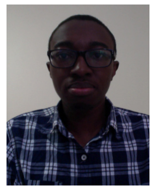
Muscle Activation Patterns for Skilled Arm Movements in Minimally Invasive Surgery



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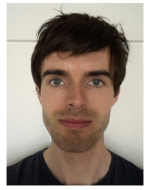
Cooperative Control of Drilling Equipment



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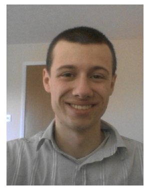
Novel Gait Analysis Metrics for the Development of Lower-Limb Exoskeleton Control Paradigms



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Confidence in Autonomous Robotics Applications

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Estimation of fluid properties using probabilistic reasoning in a general purpose robot

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Integrating Soft-Hard Hybrid Robotics

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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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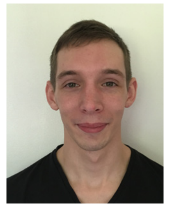

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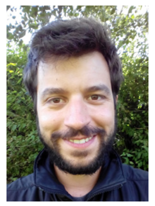

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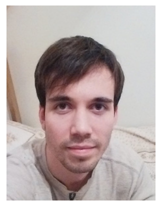

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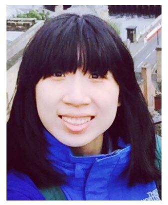

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Christoph Strassmair
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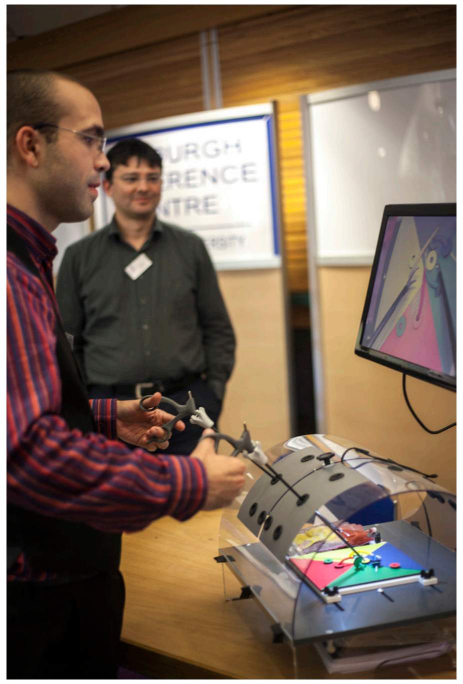
Nithiya Streethran
Pui Hang Li
Ross Cunningham
Sam Revie
Sara Trevisan
Selby Cary
Yousef Al-Nisf



Research Themes

RESEARCH
EDINBURGH CENTRE FOR ROBOTICS

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

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

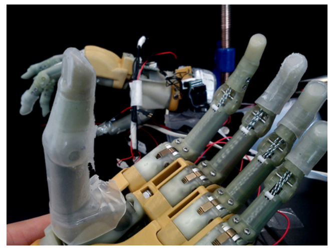
We study the sensing, world modeling, planning and control architectures that can make these robots **persistently autonomous**, operating in unknown environments for extended periods adapting their plans in response to events to complete tasks. We also investigate **shared autonomy** where people and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

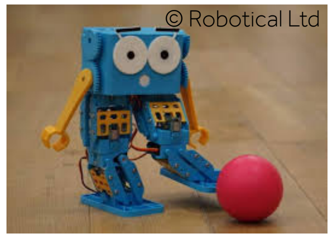
		UNDERPINNING THEORY					
	INTERACTION THEMES	Modelling & Estimation	Logic & Semantic Representation	Search & Optimisation	Learning & Adaptation	Bio-inspired Methods	Cognitive Modelling
1	**Environment Interactions:** Control, Actuation, Sensing, Planning, World Modelling	x	x	x	x	x	
2	**Multi-Robot Interactions**: 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.

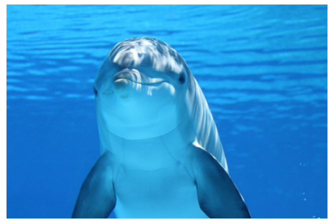


The Edinburgh Centre for Robotics through some of its constituent laboratories has a track record in activities generating this growth. Our technologies and skills have created, seeded and supported successful international businesses including SeeByte, Coda-Octopus, Hydrason and Ice Robotics, alongside 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.

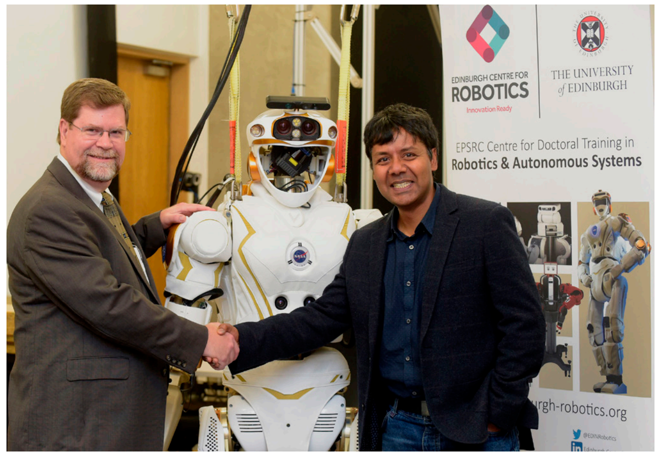
In addition to entering into discussions on RAS strategy at Cabinet Office level, Centre staff are also providing strategic advice to several large corporates and other sponsors in Offshore Energy and Security markets based on research from the Centre.



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 2015/16



Dr. Robert Ambrose, Principal Technologist and Robotics Lead, NASA with ECR Director, Professor Sethu Vijayakumar and the NASA Valkyrie on his visit to deliver the Distinguished Lecture at the Informatics Forum.

Research Area: Humanoid Robots

Humanoid Motion Planning

Supervisor: Dr Maurice Fallon
PhD candidate: Marco Caravagna

The problem we address in this work is to achieve reliable manipulation with humanoid robots. We focus on generating feasible whole-body motion plans in unstructured environments to grasp and manipulate objects avoiding obstacles.
Several methods exist to solve the motion planning problem which theoretically could be applied to humanoids. In reality, direct application of the available methods to humanoid motion planning is not straightforward because of the dimensionality of the problem and the particular constraints that need to be satisfied by a balancing robot's motion.

Approach

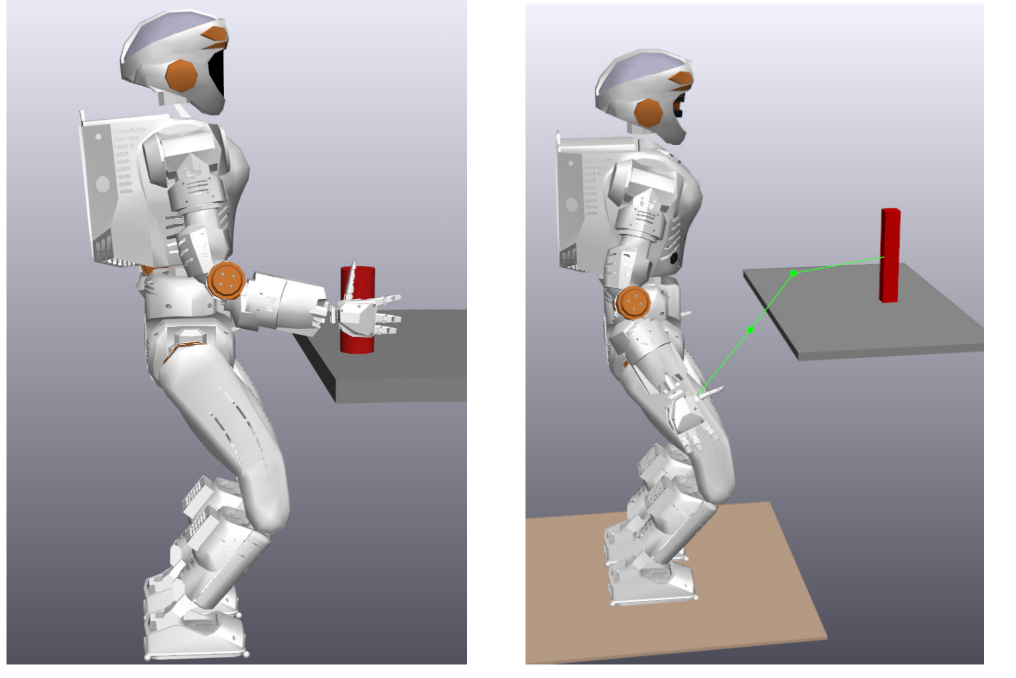
We propose three approaches based on different techniques:

- A sampling-based approach using RRT planners
- An approach based on exploitation of precomputed robot configurations
- A method based on parallelization of multiple instances of a trajectory optimization solver

In order to validate results on real hardware, experiments will be carried out on Valkyrie (Fig. 1), a humanoid robot developed by NASA with the final goal of space exploration.

Testing on the robot will assess both the robot and the planner performance on different reaching tasks. With this in mind we envisage to create laboratory environments similar to those used in simulation.

Figure 1: *The NASA Valkyrie robot*
© NASA



(a) (b)

Figure 2: *A feasible final pose to reach an object(a), and the end-effector trajectory to reach it (b)*

Results

Our contribution so far is a complete algorithm to produce whole-body collision-free trajectories for humanoid manipulation tasks. We treat the complete motion planning as two separate problems: finding a feasible final pose to reach a desired goal (Fig.2a) and computing the trajectory from the starting pose of the robot to the one computed in the previous step (Fig. 2b).

A first version of the planner has been developed in simulation and is currently under review to improve efficiency and to demonstrate on the NASA Valkyrie.

Future Work

The existing implementation presented still needs to be completed, and the results obtained in simulation have to be validated by extensive testing on a real humanoid platform. The next two years will be dedicated to the development of the other two approaches.

Impact

The goal we set ourselves is to explore different solutions to the motion planning problem specifically tailored for humanoid robots, in order to identify drawbacks and advantages of each approach. A set of publications about the results obtained with each method would outline, at the end of the PhD, a general and reliable way of computing whole body motions for humanoid manipulation.

Research Area: Virtual environments for intelligence building in robotic metrology

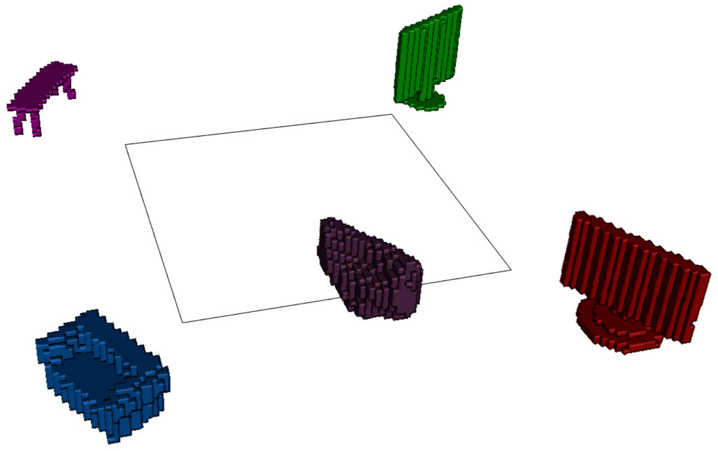
Context-aware content generation for virtual environments

Supervisor: Dr Theo Lim
PhD candidate: Andrew Brock

The objective is to develop a system capable of generating virtual content from non-expert input.
Automatic scene generation for both 2D images and 3D models is a nontrivial problem. As more intelligent automation is targeted in Industry 4.0, robots will play an important role in automated metrology. Two major challenges exist. Shop floor coordinate measurements are still reliant on manual correspondence between identifying geometric and dimensional tolerances (GD&T) from technical drawings. Computing and rendering virtual scenes involves a significant amount of in-depth, low-level manipulation of scene elements such as object vertices, edges, and faces. Both raise computationally intensive operations, and added complexities arise when dynamic content generation is required. The fundamental challenge is producing a high-dimensional image from a low-dimensional description.

Approach

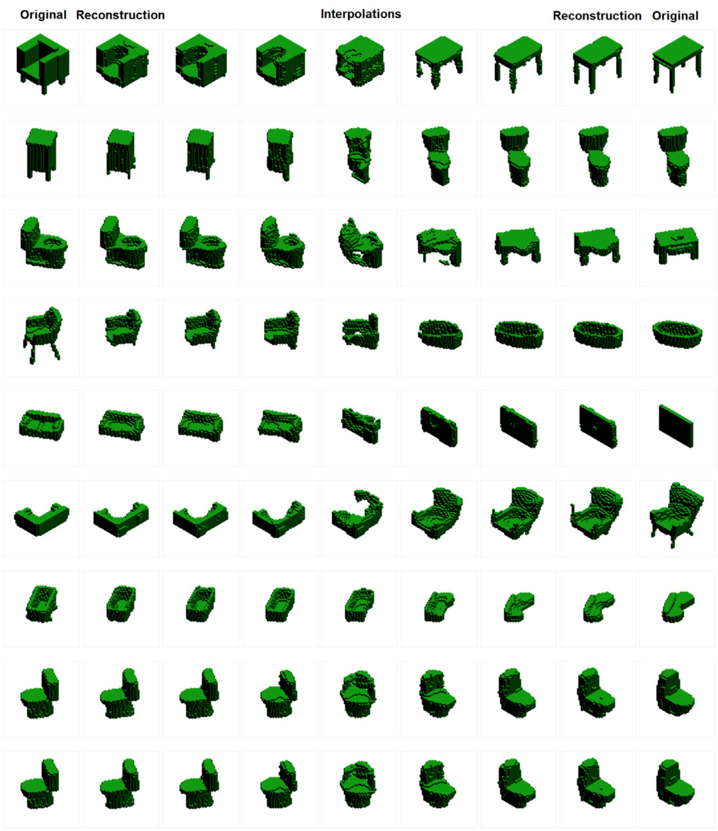
A novel 3D variational autoencoder (VAE) framework is proposed. The current implementation uses a voxel-based generative model and an interface for intuitively exploring the latent space learned by the model. This allows the VAE to learn to map a data input to a latent representation making it suitable for interpolation as well as random sampling.



The Interface

Results

After training for 100 epochs, the model achieves 99.01% mean reconstruction accuracy on the test set.



Example Interpolations
The rightmost and left most images are the original objects, the adjacent images are the network's reconstruction, and the images between show interpolations in the latent space.

Future Work

Future work will focus on augmenting the latent space with a class-conditional encoding to permit accurate generation of objects with GD&T features such as that described in 2D engineering drawings. Additionally, future work will experiment with modifications to the network's loss function to deal with the network's tendency to neglect certain object features, i.e. by making use of an adaptive or perceptual similarity metrics.

Impact

Proceedings of the ASME 2016 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, IDETC/CIE 2016, August 21-24, 2016, Charlotte, North Carolina, USA. IDETC2016-59997

Research Area: Marine Robotics

Biosonar for Object Characterisation

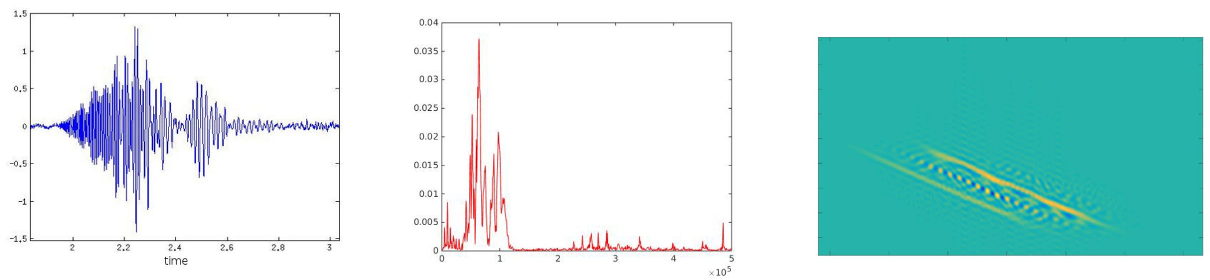
Supervisor: Professor David Lane
PhD candidate: Mariia Dmitrieva

Object characterisation is one of the challenging tasks in underwater robotics. The main attributes to characterise an object are shape, colour, material, internals and position of the target. Camera catches object's view, including shape and color, but it is a poor solution in conditions of low visibility and high distortions. Active sonar is a better solution, the distance to the object can be estimated more precisely and the shape of the object is also fine defined. The wideband sonar (Biosonar) evaluates distance to the object and its shape. Moreover it provides an information about the interaction of the target with the wideband chirp-based pulses, which helps to investigate the object's internals and material it's made of.

The bio-inspired sonar signals can be a very powerful instrument for object characterisation and recognition. The aim of the research is to study bio-inspired echolocation and develop an adaptive strategy to use the biosonar pulses to characterise an object's material and internals.
The biosonar pulses are inspired by dolphins' echolocation system. The sophisticated system allows animals to characterise and detect object, navigate in environment and avoid obstacles. Dolphins identify objects by emitting short wideband acoustic pulses, also called clicks.
The echolocation impulses have a double chirp structure. The complex signal structure allows animals to collect information about object's size, shape, and even internal content, by processing reflected pulse (response) from the object.

The click's spectrum and other parameters can be changed by the animals from click to click during the target investigation process. It allows dolphins to "tune" the clicks for better object representation.
The research applies signal processing techniques to the responses to extract information about object's characteristics.
The study is focused on simple spherical objects with a single filling, where the object's characteristics are shell thickness, shell material and filling material. We aim to see difference in energy distribution for objects with different characteristics and find a way to improve the results with adaptively tuned pulses.

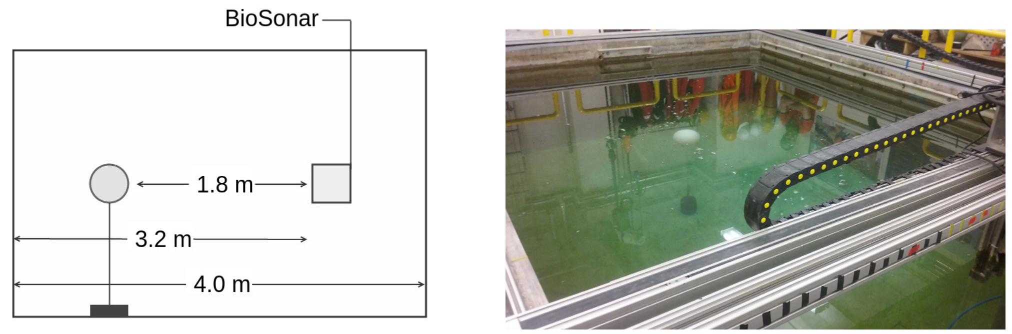
The reflected pulse, as any signal, can be presented in time, frequency and time frequency domains, fig. 1. The time-frequency domain is more convenient for the response processing. It presents changing of frequency components in time. Smoothed Pseudo Wigner-Ville Distribution is chosen as a time-frequency representation technique for the chirp based-pulses. It allows to have a decent resolution in both time and frequency domains, which makes evaluation of the energy distribution more precise.



(a) (b) (c)

Figure 1: Representation of a response in time domain (a), frequency domain (b), time-frequency domain (c)

The experimental part of the research is placed in the water tank of Ocean System Laboratory, fig. 2. The target is fixed in the water using weight and placed in front of the transmitter-receiver pair. The objects are sonified with chirp-based pulses. We change target filling and time of pulses to study the dependencies.



(a) Scheme of the test set-up (b) Picture of the tank

Figure 2: Test set-up

The final goal of the research is to develop an adaptive bio-inspired echolocation model for the object internal recognition, which involves pulse adaptation for different tasks and targets, as well as characterisation of object's material and filling itself.
The possibility to inspect internals of an object without physical interaction brings a lot of benefits for object characterisation. The technology can be used in oil and gas industry to inspect pipes, as well as for archaeology missions where some objects can be discovered distantly in a water. Other fields can also benefit from the more reliable object characterisation system.

Publication: Adaptive bio-inspired signals for better object characterisation. M. Dmitrieva, K. Brown, D. Lane. Proceedings of the Living Machines Conference, 2015.

Research Area: Myoelectric Prosthesis Control

Real-time multi-modal classification for upper-limb prosthesis control

Supervisors: Dr Mustafa Suphi Erden, Professor Sethu Vijayakumar
PhD candidate: Iris Kyranou

Objective

The majority of state-of-the-art commercial upper-limb prosthetics are controlled using surface electromyography (sEMG) techniques to record electrical activity of the muscles of the user. Although such methods are computationally simple and perform robustly, they are not as intuitive and dramatically increase the mental effort required by the user. Pattern recognition techniques have been used to analyse and map recorded sEMG activity to grasp types in a more intuitive way.
A limiting factor of pattern recognition-based myoelectric control is the lack of stability and predictability of the prosthesis performance. One way of achieving more robust pattern recognition-based control is by improving the decoder's classification accuracy. In our study we investigated the potential benefit of using novel sensory modalities for real-time myoelectric control. We provide evidence that the inclusion of acceleration, angular velocity and orientation information can improve the online myoelectric performance.

Approach

We implemented a myoelectric pattern-recognition system that records muscle activity and outputs a class corresponding to a hand pre-grasp. Commonly the muscle recordings involve only electromyographic (EMG) signals. In our system we are using the wireless Trigno™ inertial measurement sensors, which allow to record data from an Inertial Measurement Unit (IMU) data, namely data from a tri-axial accelerometer, magnetometer and gyroscope, along with the surface EMG signals.
In our project we were investigating whether the additional sensory modalities, that is, acceleration, angular velocity and magnetic field are improving the classification performance in real-time use of the prosthetic hand. In order to evaluate whether the additional sensory modality is beneficial, we trained four different linear discriminant analysis (LDA) classifiers that differed only in the sensory input they received:

- sEMG data from all sensors.
- IM data from all sensors.
- sEMG and IM data from all sensors.
- sEMG and IM data from a selected subset of sensors.

We trained each classifier on a six-class problem and tested the classifiers with a real-time pick and place experiment with both healthy and amputee subjects. The output of the classifier is translated to a pre-grasp and the corresponding command is sent to the prosthetic hand robo-Limb by Touch Bionics. Figure 1. shows one subject wearing the prosthetic hand and the Trigno sensors are mounted on his forearm and secured with elastic bandage.

Results

During the experiment, we were recording the real-time completion rate and completion time for each trial. The results are presented in figure 2.
The classifier achieving best completion rate was the one using information from sEMG and IM from 12 sensors. Interestingly the classifier that utilises combined sEMG and IM data from a subset of less than six sensors works better than the only utilising only sEMG information from 12 sensors. There is no significant change in the timing between these three classifiers. This finding is extremely important from a clinical perspective, since in real-life applications it is essential to use a minimal number of sensors.

Figure 1. Subject wearing the prosthetic hand and the sensors on his forearm. The sensors are secured with an elastic bandage.

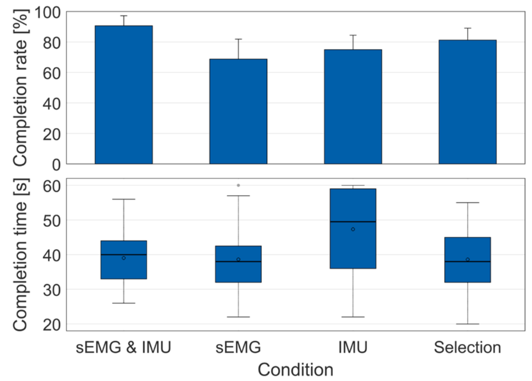


Figure 2. Top: completion rates (mean ± s.e.). Bottom: summary quartile plots of completion times. Straight lines, medians; open circles, means; solid boxes, interquartile ranges; whiskers, overall ranges of non-outlier data; solid circles, outliers.

Future Work

The system implemented in this project is parameterised and can incorporate more sensory modalities, different classification algorithms and more pre-grasp classes. Moreover, this work focused on classification, but can be extended to regression problems.

Impact

This work was published in the proceedings of the 6^th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (Biorob 2016) [1].
[1] I. Kyranou, A. Krasoulis, M.S. Erden, K. Nazarpour and S. Vijayakumar, "Real-Time Classification of Multi-Modal Sensory Data for Prosthetic Hand Control", in Conf. Proc. IEEE Int. Conf. Biomed. Robot. Biomechatron., 2016, pp. 536–541.

Research Area: Robotic Micromanipulation and Microassembly

Measurement and Characterisation of Polymer Based Electrothermal Microgrippers for Cell Manipulation and Microassembly

Supervisor: Dr Changhai Wang
PhD candidate: Muaiyd Al Zandi

The aim of the project is to develop measurement and characterisation techniques for testing and reliability studies of polymer based electrothermal microgrippers. Although design and fabrication of such devices have been studied widely, methods for reliable measurement of gripper temperature and accurate measurement of displacement have not been well established. We develop techniques for full characterisation of the gripper devices and investigate their applications in cell manipulation and in assembly of microsystems and microrobots.

Approach
We develop a temperature measurement method for electrothermal microgrippers based on the independent measurement of the TCR of the microheater and then use the result to determine the heater (gripper) temperature. An image tracking method is used to measure gripper displacement. The alignment (positioning) of the microgripper is controlled using a robotic system.

Results
The TCR of the thin film microheaters for gripper operation has been determined through independent measurements. It has been found that the value of the TCR is about half of the bulk material. Therefore it is necessary to determine the TCR of the thin film microheaters in order to determine the temperature of the heater during gripper operation. An image tracking based method has been used to measure gripper displacement for several gripper designs with sub-micron accuracy. The displacement of the grippers is in the range of 10 -20 μm.

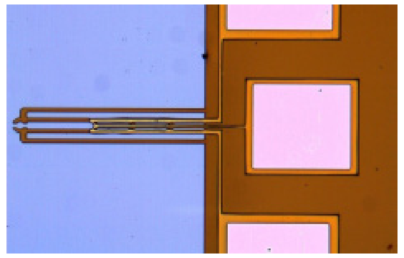
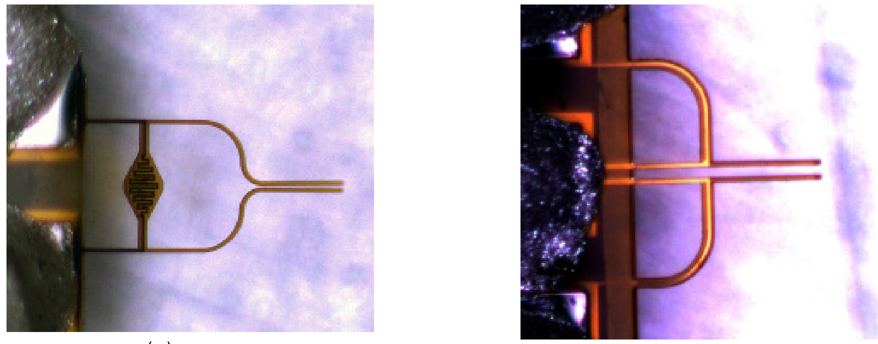
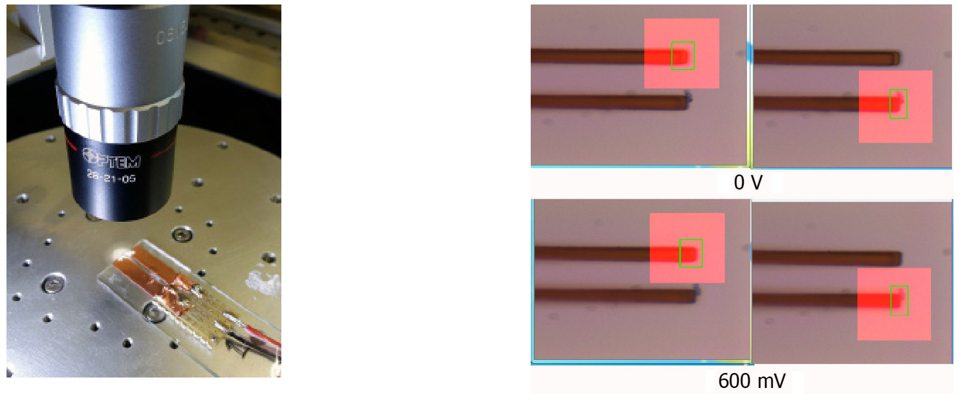


Fig. 1 An SU-8 based eletrothermal microgripper before released from substrate (IMT, Romania).



(a) (b)

Fig. 2 (a) A normally closed design, (b) A normally open design.



(a) (b)

Fig. 3 (a) Setup for gripper characterisation, (b) Image tracking method for gripper displacement measurements

Future work
The gripper characterisation capability is being developed for measurement of the dynamic response of the microgripper devices and the reliability under repeated operations. New grippers with improved performance will be developed with large displacement. Manipulation of cell like objects will be carried out to demonstrate potential applications of the electrothermal microgrippers.

Impact
A methodology for characterisation of electrothermal microgrippers has been developed. The project has led to a successful collaboration between ECR and IMT in Romania and Politecnico di Torino in Italy.

Publications
M. Al Zandi, C. H. Wang, R. Voicu and R. Muller, "Characterisation and testing of electrothermal microgrippers with embedded microheaters," IEEE Symposium on Design, Test, Integration and Packaging of MEMS/MOEMS (DTIP), Budapest, Hungary, 30 May – 2 June 2016, 7514880.
A. Soma', S. Iamoni, R. Voicu, R. Müller, M. H. M. Al-Zandi and C. H. Wang, "Design and experimental testing of an electro-thermal microgripper for cell manipulation," J. Micromechanics Microengineering, submitted, 2016.
M. Al-Zandi and C. H. Wang, R. Voicu and R. Müller, , "Measurement and characterisation of polymer based electrothermal microgrippers," Microsystem Technologies, submitted, 2016.

Research Area: Soft Systems

Lowering the Barrier to Entry for Soft Robotics

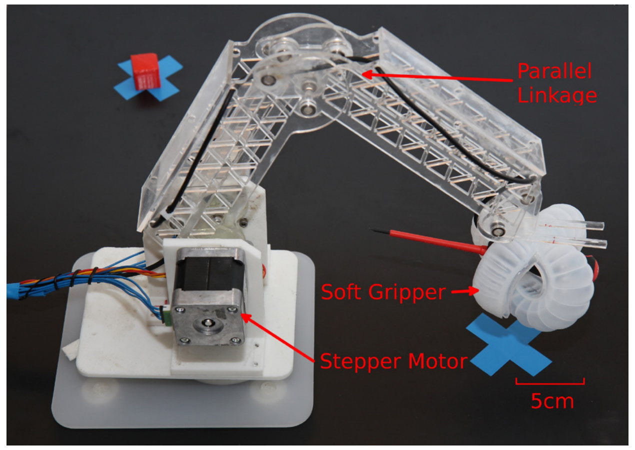
Supervisor: Dr Adam A. Stokes
PhD candidate: Ross M. McKenzie

Making Soft Robotics More Accessible

Soft robotic components can have numerous benefits over their conventional counterparts as they provide safe and robust systems. However, the adoption of soft robotics by the wider research community has been slow and has been even slower in commercial robotics. One reason for this delay is the fact that soft robotic components require their own specialist software and hardware that is currently custom made for each new system. We are working to lower this barrier to entry by providing open source hardware and software.

Why use Soft Robotics?

Soft robotics revolves around working with robots whose materials or structure stray from traditional wheeled or rigid link robots. Robots that are not rigid are more robust and are able to interact with delicate objects safely. Designing robots with non-conventional materials and techniques also allows for the embodiment of intelligence, which means offloading complex tasks from the robot's CPU by making its body able to automatically execute those tasks. One example of this is found in soft robotic grippers; the soft robotic fingers on these grippers automatically conform to the shape of a grasped object. This conforming provides a more stable, enveloping grasp which would be computationally expensive if performed with rigid-link jointed fingers.



Our hard-soft hybrid arm

An Open-Source, Soft-Hard Hybrid, ROS Enabled Robotic System

Soft-hard hybrid robotic systems can use the advantages of both hard (speed, precision) and soft (durable, flexible) robotics. Our approach to lowering the barrier to soft robotics is to create a hybrid platform whose software and design will be open sourced. By making the system modular we provide a variety of options to researchers, from a full autonomous system to easily integrated components with specific function. We decided to build the software using ROS as it makes all of our modules, and the system as a whole, easy to integrate with existing robotic systems.

We are currently working on a soft-hard hybrid robotic arm for pick and place tasks. We chose a pick and place task to demonstrate our system as pick and place tasks are common in industry and many have still not been automated. The reasons for the lack of automation in these cases often comes down to the target objects being too delicate or inconsistently shaped for standard robotic grippers; both of these problems could be solved with soft robotic grippers.

The Results from Our Early Development

We currently have a working a soft-hard hybrid robotic arm and have open-sourced the design and software; these resources are available at:
http://www.homepages.ed.ac.uk/astokes2/research_BSR.html#ROS.
The video results from two pick and place tasks can be viewed at:
http://edin.ac/2cKLWKS and http://edin.ac/2ccasze

These videos demonstrate that the arm can pick up two objects with different shapes using the same control input to a soft gripper. Performing this task with a conventional gripper is only possible with precise prior knowledge or using grasp selection algorithms. One video also shows the arm manipulating a delicate object (a tomato) without damaging it thanks to our use of a soft robotic gripper.

What's Next for the Hybrid System?

Our design of the system makes it very easy to add in new software and hardware components and so we will be adding new modules for other soft robotic actuators and sensors. Our other work will revolve around making the system even more accessible through tutorials and documentation on setting it up.

The Impact of Our Open Source Robot

This open source system is ideally placed to allow those in the Informatics community to start working with soft robotics. Previously anyone hoping to work with soft robotics would need to engineer a bespoke control system and code it themselves which is a barrier that would put many off, especially those used to off the shelf components. We are also planning on publishing our work and further extensions to the system will lead to further publications.

Research Area: Humanoid Robots

Humanoid Visual SLAM Fusing Proprioception

Supervisors: Professor Yvan Petillot, Dr Maurice Fallon
PhD candidate: Raluca Scona

The objective is to develop a robust visual SLAM method for a humanoid robot within a room-sized environment.
This problem is important because high accuracy localisation is fundamental for a successful operation, while access to a map enables the robot to reason about its environment and have a high degree of autonomy.
Challenges to visual SLAM within the humanoid context include motion blur in the camera image introduced by sudden motion, a lack of visual features in man-made environments as well as dynamic elements.

Approach

The hypothesis is that fusing proprioceptive information within a visual SLAM method will lead to more robust localisation and higher quality maps for a humanoid robot.
By taking advantage of kinematic-inertial information, classic visual SLAM challenges such as motion blur or dynamic elements can be overcome.
The platform is the Valkyrie humanoid robot which has 32 degrees of freedom, force-torque sensors on the feet, joint encoders in every joint, an inertial measurement unit in the pelvis and a high resolution stereo camera in the head (figure-1).

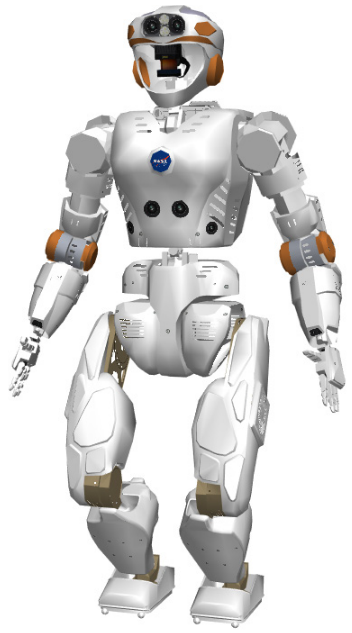


Figure 1: Valkyrie Humanoid robot

Results

1. Kinematic-Inertial State Estimation
Our kinematic-inertial state estimator has been configured to run on Valkyrie with a translational drift of 1cm for every 2m travelled.

2. Visual SLAM
The ElasticFusion dense visual mapping method (Whelan et al. RSS 2015) has been configured to run using stereo data and preliminary evaluations have been carried out on the humanoid (Figure 2).

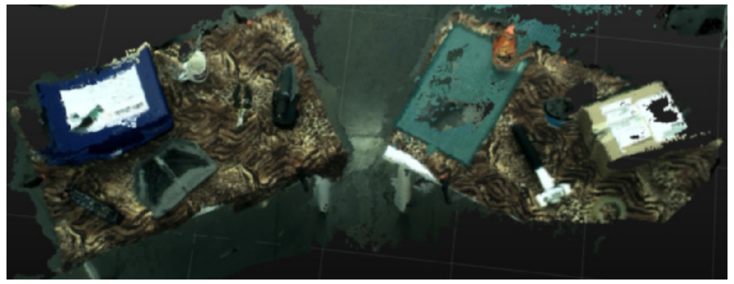


Figure 2: Example reconstruction using ElasticFusion

3. Stereo Disparity Filtering
The disparity map produced by the stereo camera is filtered to remove areas with low texture, small unconnected components as well as robot self-detection (Figure 3).

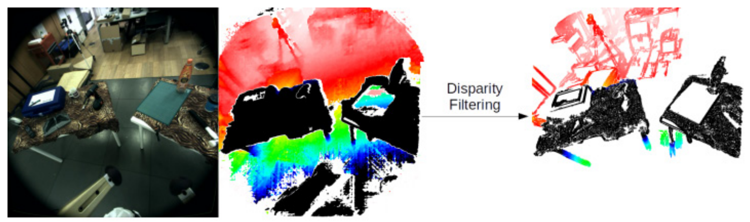


Figure 3: Filtering the disparity map to remove textureless regions

Future Work

Future work consists in researching methods for fusing visual and kinematic-inertial tracking in order to handle dynamic elements as well as motion blur.
Long-term goals also include researching methods for reducing the space requirement for the map representation.

Impact

The goal is to achieve a robust visual SLAM method to enable the robot to safely navigate a room-sized environment. The results obtained through this approach will be published within scientific conferences and journals.

Research Area: Machine learning, Underwater Robotics

Increasing Robustness of Autonomous Systems to Hardware Degradation Using Machine Learning

Supervisor: Professor David Lane
PhD candidate: Georgios Fagogenis

Objective

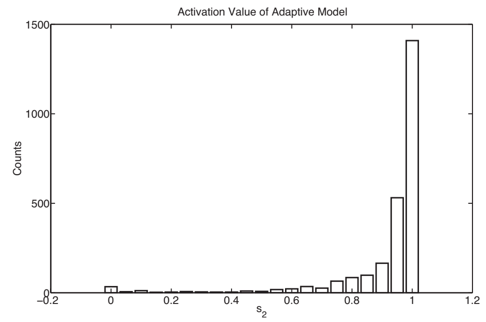
The objective of this work is to develop algorithms that will help increase the robustness of an autonomous system to hardware degradation (sensor and actuator failures). Specifically, using the developed algorithms, the autonomous agent ignores measurements from faulty sensors, and uses the dynamical model instead; whereas, in the case of actuator failures, the agent can detect the problem and learn a new dynamical model -one that accommodates the detected fault- online. In this way the autonomy level of the robot is increased significantly; i.e., the robot can carry out the designated mission even in cases of hardware failure.

Approach

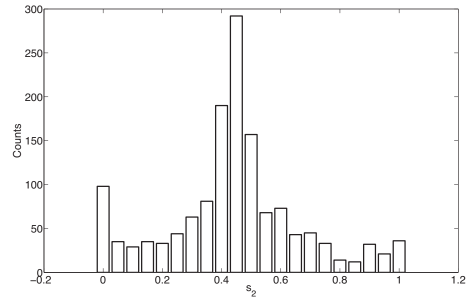
To achieve robustness to hardware failures, we used Bayesian filtering to infer the state of the robot. All involved variables are considered to be random, and they are given an appropriate prior distribution; i.e., an initial guess of the possible values the variable may get, in the form of a probability distribution. A set of assumptions is then used to model the interactions between these random variables. The observed variables, namely the sensors, are used to correct the model predictions. The final output for the state depends on the uncertainty of the prediction and observations. The presented framework adjusts the uncertainty of prediction and that of the sensors in real-time using recent state information. Moreover, instead of a standard model for the prediction step, we employed a set of models realized as a mixture of Gaussians. In a minimal example of two models, one model would be the nominal and the other one will constantly adapt online; proper care is taken to avoid adapting the model when the sensors are defective. The adapted model reflects the robot's dynamics accurately at a given moment. Then using Bayesian inference, we compute which model most accurately explains the incoming data from the sensors. In a normal situation when all robot hardware is working properly, the nominal model prevails; whereas, following an actuator failure, the adapted model is more accurate. In this way, fault detection is combined with learning the new model in real-time.

Results

Choosing between the two models is implemented using a switch variable, which is in fact, a variable between zero and one; zero indicating the nominal model, and one indicating the adapted. In the case where no failure occurs, the two models are identical; both equal to the nominal model. Hence, in this case, the switch variable will be equal to 0.5. Below we show the distribution of the switch variable on data gathered using an underwater vehicle (Nessie). On the first experiment, we artificially introduced a thruster failure: the output of the thruster was capped to 57% of the thruster's nominal output. As seen in the top image, the algorithm correctly identified the fault; the distribution of the switch variable is concentrated around one. Conversely, the image at the bottom shows the distribution of the switch variable for an experiment that everything was normal. In this experiment both models agree with sensor observations; hence, the distribution of the switch is centered at 0.5.



(a)



(b)

Distribution of the switch variable a) in the presence of a fault (left) b) during normal operation

Future Work

The presented algorithm can keep the vehicle operational even in cases of hardware failure. The faults can be detected and mitigated for the state estimation; i.e., about computing where the robot is but it does not actively remedy the fault in the control level. Since the algorithms learn a model for the fault, we plan to use this new model to drive the vehicle in case of thruster failures. We will apply simple control schemes, and use the newly learned model to show that we can stably control the robot even if the actuation system fails partially.

Impact (Related Publications)

Fagogenis, Georgios, David Flynn, and David M. Lane. "Improving underwater vehicle navigation state estimation using locally weighted projection regression." 2014 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2014.

Fagogenis, Georgios, David Flynn, and David Lane. "Novel RUL prediction of assets based on the integration of auto-regressive models and an RUSBoost classifier." Prognostics and Health Management (PHM), 2014 IEEE Conference on. IEEE, 2014.

Fagogenis, Georgios, and David Lane. "A Variational Bayes approach for reliable underwater navigation." Intelligent Robots and Systems (IROS), 2015 IEEE/RSJ International Conference on. IEEE, 2015.

Fagogenis, Georgios, Valerio De Carolis, and David M. Lane. "Online fault detection and model adaptation for Underwater Vehicles in the case of thruster failures." 2016 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2016.

Ocean Systems Lab trials with Nessie
Image courtesy of Len McLean

Research Area: Visual Navigation

Navigation and Mapping of Natural Environments

Supervisor: Prof Barbara Webb
PhD Candidate: James Garforth

The aim of this work is to improve robotic navigation techniques for use in entirely natural environments, such as forests. It is undertaken in collaboration with neuroscientists tracking animals for behavioural experiments and geoscientists performing large scale forest monitoring.

There is a great deal of literature in robotics on visual Simultaneous Localisation and Mapping (SLAM), but the common environments for their use are well-organised and structured by human beings, so the solutions produced do not necessarily perform well in complex, dynamic natural environments. We are investigating the limitations of the state of the art in this setting and developing improvements to address them.

Approach

Our approach involves undertaking an analysis of the performance of existing state of the art navigation systems on new natural environment datasets, collected by us. It is expected that the performance of these systems will be poor due to a number of factors, including:

An example frame from the forest navigation datasets gathered for this work.

- Visual similarity between places in the environments.
- Changing conditions over time (lighting, weather, etc).
- Highly dynamic scenes; moving grass, leaves, branches.

Starting with the first of these limiting factors, we are comparing existing techniques and using the lessons learned to produce new algorithms for SLAM that have robust performance in difficult settings. Working with our industry collaborators, we will demonstrate the effectiveness of our system at allowing a drone to navigate and map managed forests.

Parrot's "Bebop" drone: small, low cost, with a wide field of vision, this is our current platform for mapping forests.

Results

Initial work focused on tracking the pose of a hand held camera looking down at a natural scene. The videos being used are part of insect behavioural studies where extracting the path of an ant through the world is crucial. State of the art ORBSLAM can track the motion of the camera but experiences drift and is unable to recognise places it has already visited in order to perform corrections. Similar results have been seen for forest videos.
We are currently comparing a variety of place recognition techniques on our datasets, to learn what methods will be able to compensate for ORBSLAM's weakness.

Future Work

Once our comparative review is complete, we intend on producing a hybrid SLAM system that combines ORBSLAM's local map building with an improved method for place recognition to correct for drift. After this, we will expand our system to perform dense, more detailed reconstructions of scenes so that the resulting map can be used intuitively by human operators for measurement or other visual data extraction.

Impact

The finished PhD work will consist of a series of publications outlining improvements to robotic navigation approaches for forests, and it is expected that some of these will generalise outside of this domain. Our collaborators in Geospatial Imaging will be able to license this technology and leverage it for their clients, gathering more complete data about the health of managed forests. Likewise, research groups studying animal behaviour will be able reliably track the location of cameras used to record animals in their natural habitats.

Research Area: Rehabilitation Robotics

Shared control paradigms for exoskeletons

Supervisor: Professor Sethu Vijayakumar
PhD candidates: Graham Henderson and Daniel Gordon

Millions of people have gait disorders that decrease their mobility and hinder the ability to lead a full independent life. These disorders can be due to either pathologies (for example, stroke, cerebral palsy, or spinal cord injury) or due to aging. Exoskeletons have the potential to improve mobility and therefore restore the ability to undertake activities of daily living.

For an exoskeleton to augment movement, a shared control paradigm is required to determine the timing and magnitude of assistance for an individual. Generating the desired trajectory that is task appropriate and suitable for the individual is challenging due to natural variations in human gait [1].

Approach

We propose approaches based on experimental and computational techniques:

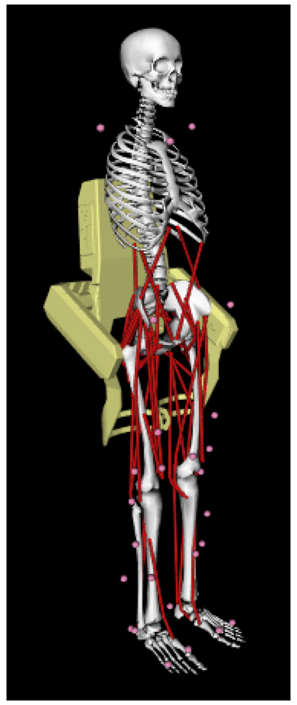
- Use experimental data and optimisation techniques to disambiguate between human torques and exoskeleton torques.
- Using the hierarchical stack of tasks framework [2] for whole-body control, derive an analytical model of a human/ exoskeleton system.
- Use the above framework and experimental testing to determine a metric for measuring gait optimality.

The results from the above techniques will be used to develop a shared control paradigm for testing with patients. For the experimental testing we have a world class gait testing facility, this includes a Motek Medical fully instrumented split treadmill, Vicon full body motion capture system and Delsys wireless EMG system. We additionally have two pieces of exoskeleton hardware, including the active pelvis orthosis (APO) developed in collaboration with IUVO and the active ankle foot orthosis (AAFO) designed in-house and manufactured in collaboration with Shadow Robot Company.

Active pelvis orthosis

Results

- Created an OpenSIM model consisting of a human walking with an active orthosis constrained to the body.
- Using the hierarchical stack of tasks framework for whole-body control, created an analytical model of a human/exoskeleton system which was used to forward simulate walking.
- Disambiguated between the human and exoskeleton contributions to the net torque using a weighted optimisation framework.
- An algorithm was developed using the experimental data to map from an error value in the metric to an APO torque command.



Human and APO model created in the OpenSIM software [3]

Future work

The stack of tasks framework will be adapted to specify adjustments to APO torque values in real-time, in order to drive a subject's gait towards a desired gait according to some metric. Additional work is to identify a metric invariant to natural variations in gait using both the experimental and analytical frameworks. This metric will be used as part of a real-time visual biofeedback system to encourage subjects to adapt an optimal gait.

Experimental data capture setup

Impact

Successful outcomes could lead to control paradigms for exoskeletons which are appropriate for a range of different embodiments, environments and gait pathologies. This will ultimately improve device usability and help to reduce device abandonment.

Another use of the developed metric and OpenSIM model is for testing and ranking different types of active orthoses and prostheses. This could be developed into a tool to guide clinical decision making in relation to equipment selection.

References

[1] R. Jimnez-Fabin and O. Verlinden, "Review of control algorithms for robotic ankle systems in lower-limb orthoses, prostheses, and exoskeletons," Medical Engineering and Physics, vol. 34, pp. 397-408, May 2012.
[2] L. Saab, O. Ramos, N. Mansard, P. Souères and J-Y. Fourquet, "Generic dynamic motions generation with multiple unilateral constraints," IEEE/RSJ International Conference on Intelligent Robots and Systems, San Francisco, California, USA, 4127-4133.
[3] S. L. Delp, F. C. Anderson, A. S. Arnold, P. Loan, A. Habib, C. T. John, E. Guendelman, and D. G. Thelen, "OpenSim: open-source software to create and analyze dynamic simulations of movement," IEEE transactions on bio-medical engineering, vol. 54, pp. 1940–1950, Nov. 2007.

Research Area: Industrial Robotics

Development of a handling system for ultra-precision machining

Supervisors: Dr Xianwen Kong and Dr Matthew W. Dunnigan
Research Associate: Dr Ross Walker
PhD Candidate: Mr Xavier Herpe

Objective

The project is to develop an automated system for the handling of materials and parts in an ultra-precision machining and assembly centre. The system will be required to pick and place the machining work piece holder, materials for machining, and machined parts. Hence, the size of parts varies from 2mm glass macro-lenses to 55mm length metal workpiece holders. The manipulation of such pieces presents a challenge for the development of a gripper with a large range of jaw pitch and applied force. Additionally, the material handling system will be required to fasten screws on the workpiece holder while holding raw material in place.

The specifications for the handling system were as follows:

- Pick and place parts with dimensions between 1mm and 55mm.
- Maximum pick and place payload of 1.2kg.
- Positioning accuracy of less than 100μm.
- Fasten screws on workpiece holder up to a torque of 5Nm

Approach

The material handling system will use an Epson SCARA ES series as manipulator with an Epson SRC-320 controller. This robot has a maximum reach and payload of 650mm and 5kg, with positional and rotational repeatability of ±30μm and 0.03°, respectfully.

Fastening of the four screws on the workpiece holder has been achieved by applying torque from a stepper motor with a 25:1 reduction gearbox. This applies torque to each screw individually in the range of 0.175Nm to 5.82Nm. Positioning of the stepper motor is done so using an XY stage, with an accuracy of 120μm and repeatability of 30μm. Clearly, this system meets the specification required for fastening of the workpiece holder screws.

A prototype gripper has been developed which uses compression springs to augment the effective force applied to parts with dimensions less than 16mm. The designed gripper uses a crank and four-bar linkage to achieve parallel gripping with a pitch of 150mm. A DC motor is employed as method of actuation and can apply torque up to 1.5Nm. Digital quadrature encoders provide position feedback to an accuracy of 0.36°. Furthermore, PID and PI control were implemented on an Ingenia Pluto servo drive which would allow the gripper to be position or force controlled, respectively. When the part is configured in the jaw such that compression springs are used, the force from the gripper can be applied in the range of 2.8N to 9.4N. The specified force to be applied to the macro glass lenses was less than 20N. Hence, the force applied by the gripper will not damage these parts. When the compression springs are not engaged the gripper can apply forces from 21.1N to 74.4N. Hence, this force range will provide adequate gripping force for larger parts.

The complete system has been integrated to be run from a single computer using Labview. Figure 1 presents the component parts of the handling system and a schematic diagram of their integration.

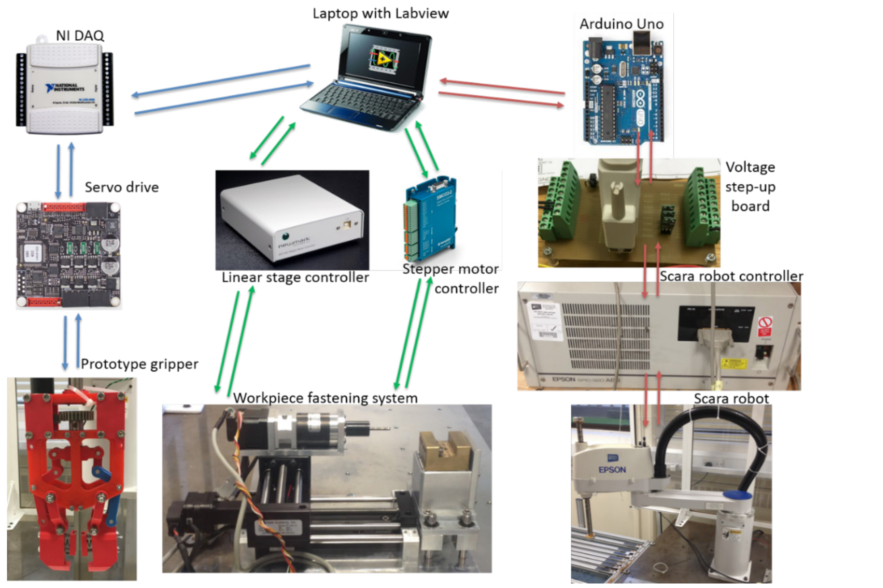


Figure 1: Component parts of the handling system and schematic diagram of their integration

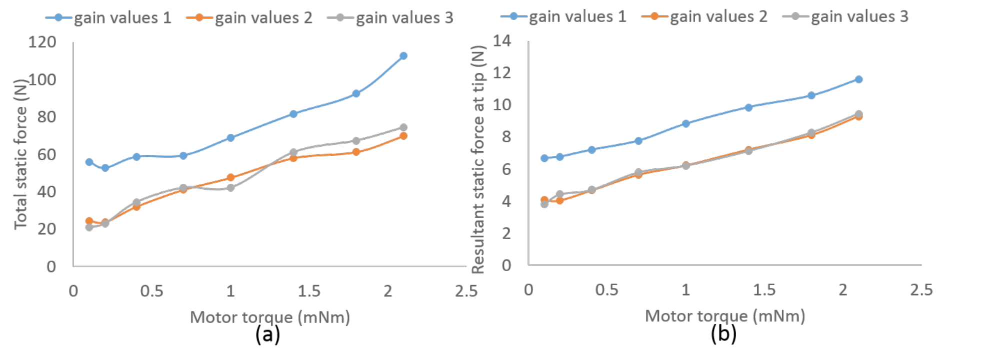


Figure 2: (a) The total force applied by the gripper and (b) The effective force applied at the tip of the gripper as a result of force reduction from the gripper's compression springs.

Results

The force applied by the gripper was determined by the measuring the displacement of a spring compressed by the jaw of the gripper using a coordinate measuring machine (CMM). Figure 2 presents (a) the total force applied by the gripper and (b) the effective force applied at the tip of the gripper as a result of force reduction from the grippers compression springs. This measurement was carried out using three sets of PI gain values.

Future Work

Future work will involve the inclusion of a machine vision system with the SCARA robot to allow for positional feedback and correction. The material handling system will then be integrated with the machining centre, currently under development at the University of Strathclyde.

Acknowledgements

The authors would like to thank the Engineering and Physical Sciences Research Council (EPSRC), United Kingdom, for supporting this work under grant No. EP/K018345/1.

Research Area: Medical Robotics

Muscle Activity of Skilled Arm Movements in Minimally Invasive Surgery (MIS)

Supervisor: Dr Mustafa Suphi Erden
PhD Candidate: Derek Chun

Objective

The feasibility of using muscle activity to assess Minimally Invasive Surgery (MIS) manipulation skill level was investigated in this study. A group of complete novice subjects was trained to provide the skill level increase. The muscle activity was assessed by surface Electromyography (s-EMG) before and after training. The muscle activity characteristics attributed to skill improvement were observed. The differences in muscle activity for skilled and unskilled showed that s-EMG could potentially provide an objective skill assessment measure for MIS.

Approach

A minimally invasive surgery box trainer as shown in Fig. 1 was used to create the MIS environment. It is commonly used by surgeons to train MIS dexterity skills. The video capture function enabled visual analysis after training.
A training game, "Hoop transfer" was selected with the input of the expert surgeons from Cuschieri's Skills Centre in Dundee. The difficulty was suitable for complete novices and effective improvement with low amount of training.
An accelerometer was mounted on the training platform to quantify accuracy (amount of disturbances to the platform).
The Cometa Wireless EMG recorder was used. The wireless system reduced potential noise.
A group of complete novice, right-handed, subjects were selected. The training consisted of three training sessions. Assessment sessions with s-EMG instrumentation was performed before and after the training sessions to observe the changes in muscle activity.
The video data were analysed and the times of the discrete events, pick-up and drop-off (placed) of the hoops were extracted.
The accelerometer of the training platform combined with the number of successful transfers provided the performance data to show improvement after training. A higher skilled individual could achieve a higher number of transfers and lower disturbances to the platform.
The s-EMG data was applied to Lateral Deltoid, Biceps, Triceps, Extensor Digitorum (ED) and Flexor Carpis Radialis (FCR). A frequency power spectrum was derived based on the 0.128s time window around the event time. The peak muscle activity provided an indication of the level of muscle activity. The peak muscle activity was averaged across all the events (pick-up and drop-off respectively) to observe the difference in muscle activity.

Results

The performance data showed a significant improvement after training. The upper arm muscles activity showed little changes after training. The forearm muscles activity showed a decrease in activation at pick-up events as shown in Table 1. The subject commented that after training, the training game was easier and lower arm was less prone to fatigue. In the drop-off event, the Extensor Digitorum (ED) activity reduced but the Flexor Carpis Radialis (FCR) activity increased as shown in Table 2. The increase in FCR muscle activity at drop-off could be attributed to the improvement in performance, such as accuracy or speed or both. Both the increase and decrease of muscle activity at different fore-arm muscles suggested that there could be an optimal muscle activity level at different events (dependent on the motion).

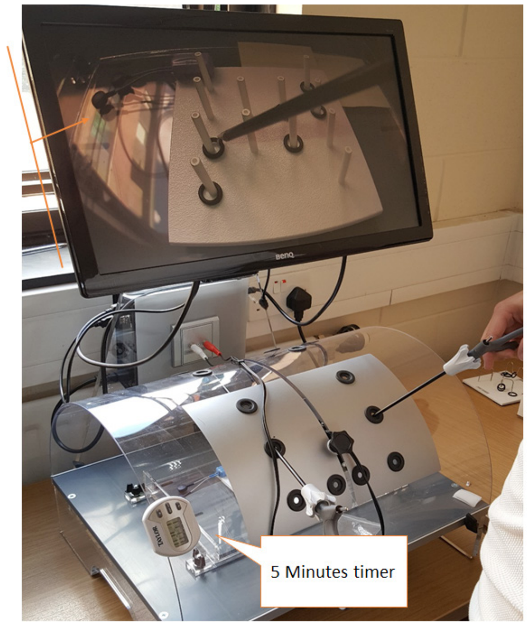


Figure 1: The laparoscopy box trainer

Description		Before Training	After Training	Change
Subject and muscle at Pick-up		*Averaged peak activity (μV)*	*Averaged peak activity (μV)*	*% decrease*
A	ED	5602	2671	**52%**
B	ED	3615	2545	**30%**
C	ED	7625	1865	**76%**
A	FCR	871	506	**42%**
B	FCR	1396	780	**44%**
C	FCR	1534	1285	**16%**

Table 1: Muscle Activity Change at Pick-Up

Description		Before Training	After Training	Change
Subject and muscle at drop-off		*Averaged peak activity (μV)*	*Averaged peak activity (μV)*	*% decrease*
A	ED	3034	2092	**31%**
B	ED	5073	2536	**50%**
C	ED	3559	1762	**50%**
A	FCR	1229	1778	**-45%**
B	FCR	954	1068	**-12%**
C	FCR	1641	2307	**-41%**

Table 2: Muscle Activity Change at Drop-Off

Future work

The project could extend into more difficult procedures with higher initial skill level subjects such as, trainee surgeons. It could highlight accuracy related muscles to define a set of exercises to training on. In addition, the project could highlight muscles where the activities were high and could be reduced to delay the effects of fatigue. An expert surgeon could also define the expert muscle activity level for different events to reinforce the observations made in this project.

Research Area: Humanoid Robotics

Efficient Full Body Motion Planning for Humanoid Robots in Dynamic and Complex Environments

Supervisor: Professor Sethu Vijayakumar
PhD students: Yiming Yang and Wolfgang Merkt

Objectives

For humanoid and mobile robots, it is important to take full advantages of the moveable base for grasping and manipulating distant objects. However, it is non-trivial to find appropriate pre-grasp stance and grasping postures in complex and cluttered environments, which typically needs to be specified by human operators. Towards better robot autonomy, it is essential to automatically find such end–poses in order to invoke walking controller and motion planners. We also address the actual motion planning problem to generate collision-free and balanced whole-body motion for humanoid robots.

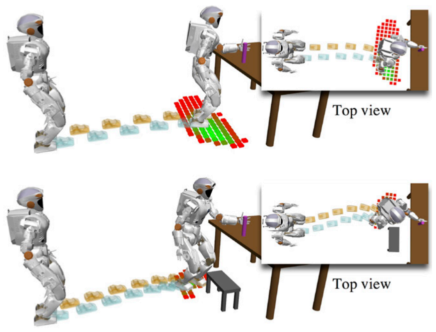


Figure 1
Find appropriate end-poses i.e. stance

Figure 2: Collision-free and balanced whole-body motion.

Approach

- We developed a new algorithm, namely the Inverse Dynamic Reachability Map (iDRM), that is capable of planning appropriate end-poses in complex environments in real-time (Figure 1). This is crucial to provide the necessary input to footstep and motion planning algorithms and be reactive to changes in the environment.
- We also proposed a new approach that scales up existing sampling-based motion planning algorithms to generate collision-free and balance whole-body motion for high degree-of-freedom humanoid robots, as shown in Figure 2.

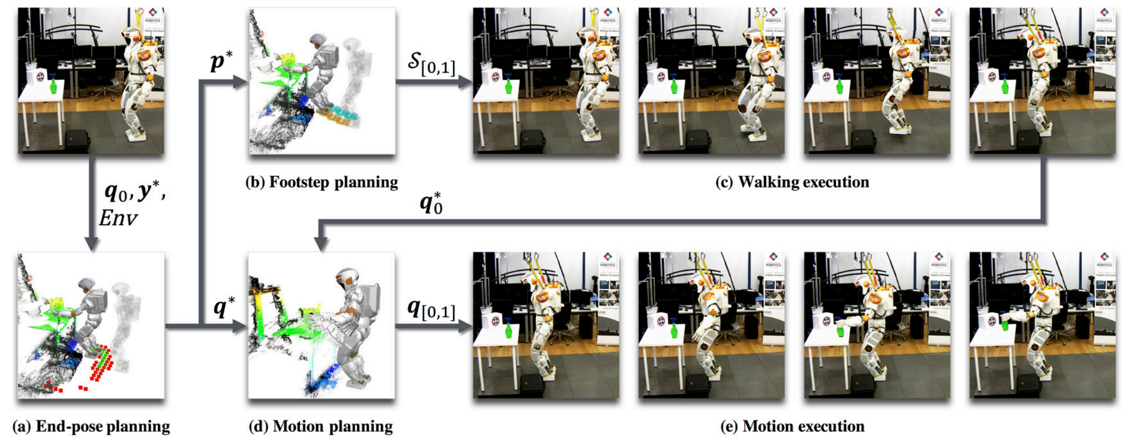


Figure 3 Humanoid motion planning framework overview

Result

We have integrated the proposed end-pose planning and motion planning algorithms to form a humanoid planning framework as highlighted in Figure 3. We have implemented these solutions on the NASA Valkyrie Humanoid Platform, operating in real time under clutter. The result (Table 1) shows that the proposed method is capable of finding valid solution much faster than existing approaches.

Tasks / Algorithms	Easy	Medium	Hard
Random Place	0.1916	1.2322	2.2654
Random-DRM	0.7521	2.3273	38.8050
IRM	0.0440	0.9560	2.2910
iDRM	**0.0553**	**0.0566**	**0.0678**

Table 1 End-pose planning time in seconds

Impact

By introducing efficient end-pose planning and full body motion planning algorithms, we hope to improve robot autonomy. Instead of having operators command and monitor every action, the robot should be able to reason about the tasks and environments, and find its own way to approach and reach the target while satisfying demanding constraints.

Future work

Our current algorithm, and other existing methods, consume a significant amount of memory during runtime. The next step is to develop more advanced processing and indexing techniques that require less memory. Another research direction is to parallelize end-pose planning as well as motion planning algorithms to further improve online planning efficiency.

Publications

Y. Yang, V. Ivan, W. Merkt, and S. Vijayakumar, "Scaling Sampling based Motion Planning to Humanoid Robots," IEEE ROBIO 2016
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 Humanoids 2016

Research Area: Marine Robotics

Cleaning our Oceans: Autonomous Underwater Vehicles for Submerged Marine Debris Recovery

Supervisor: Professor David Lane
PhD Candidate: Matias Valdenegro-Toro

Objective

Many scientists have made reports about human-made garbage being found in the deep ocean, at depths of up to 4000 meters underwater. Garbage does not occur naturally in the deep ocean, as it is mostly dropped, by accident or on purpose, by ships and vessels, or carried away by rivers passing through cities, or just moved by currents that pass near beaches and populous shores. Submerged garbage or at sea is denominated marine debris.

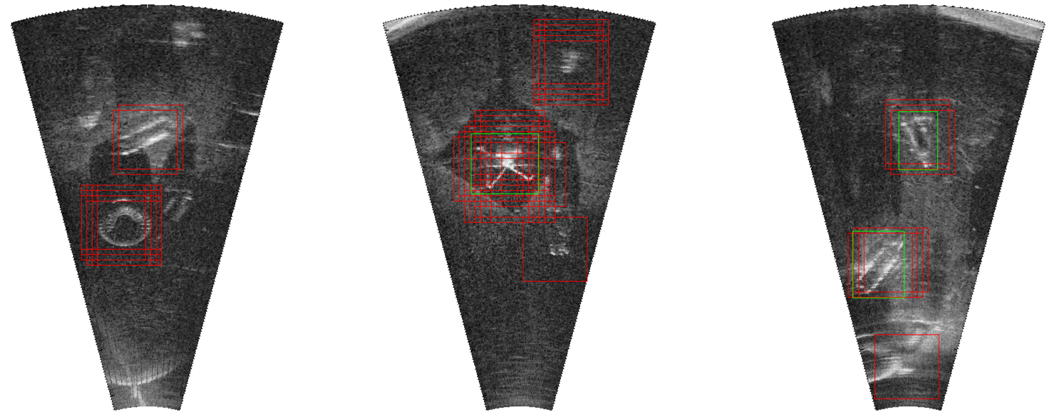
The effects of marine debris in the environment are well known. The biggest polluting material is plastic, as it has a long degradation period (hundreds of years) and can break down under sunlight into small particles that are consumed by marine animals. Some of these marine animals (fish) are consumed by humans and can transport plastic particles into the human body. Other kinds of materials, like metals, pollute waters and reduce the amounts of fresh water that is available to human populations.

Polluting our environment is clearly not a sustainable option, and completely eliminating garbage that is discarded at sea and rivers is an objective that we must pursue. But still there is the problem of collecting all marine debris that has been dropped by humans, and discarding it properly. Divers cannot do this as it would take a large amount of resources and would risk human lives. Autonomous Underwater Vehicles (AUVs) can perform such job for us. An AUV equipped with an adequate sensor could detect submerged marine debris, and using a manipulator arm, it could collect the piece of debris and store it for later processing. This kind of technology would not be expensive and could perform the task on large sections of the sea floor without major issues.

Approach

Large advances in both perception and manipulation in underwater environments are required to detect and recognize marine debris, and use a robot manipulator to collect it. In my PhD research I only concentrate on detection and recognition of marine debris, using two technologies:

- **Forward-Looking Sonar**
  Sonar sensors use acoustic waves to sense the environment. I am using the ARIS Explorer 3000 FLS as it has the best resolution (3 mm) to detect small objects as marine debris.
- **Deep Neural Networks**
  This kind of neural network has revolutionized object detection and recognition in color images, and my research is about applying them to detect and recognize marine debris in sonar images. Sonar imagery is very different from normal images produced by cameras and need special interpretation that can be learned with a neural network.



(a) Bottle and Tyre (b) Underwater Valve (c) Bottles

Figure 1: Detection and Recognition of Submerged Marine Debris with Deep Neural Networks

Results

I have developed several neural network architectures that can detect and recognize small objects in sonar images.
As shown in Figure 1, my neural networks can be trained to detect the marine debris samples that we have in our laboratory setup, and even to classify them correctly. Up to 85% of marine debris can be correctly detected and 70% of it is correctly classified.
I have also started exploring other uses of neural networks in AUV perception, such as tracking objects as the robot moves over the sea floor.

Future Work

There is a lot of work to be done in this field. My networks can only detect objects if they have a predefined size or smaller, and this limitation should be removed in further research. I have also assumed that the objects have aspect ratio close to one. The datasets we have collected are small (2000 images) and we are already planning trials at canals in Edinburgh, Amsterdam and Paris to collect data in real environments. I also plan to extend my work to journal submissions.

Impact

Objectness Scoring and Detection Proposals in Forward-Looking Sonar Images with Convolutional Neural Networks, Accepted in Proceedings of Artificial Neural Networks in Pattern Recognition: 7th IAPR TC3 Workshop, ANNPR 2016. Ulm, Germany, September 28-30, 2016.

End-to-End Object Detection and Recognition in Forward-Looking Sonar Images with Convolutional Neural Networks, Accepted in IEEE/OES Autonomous Underwater Vehicles, Tokyo, Japan, November 6-9, 2016.

Submerged Marine Debris Detection with Autonomous Underwater Vehicles, Accepted in International Conference on Robotics and Automation for Humanitarian Applications. Kerala, India, December 18-20, 2016.

Following papers are under review or to be submitted:

Matching Sonar Image Patches via Convolutional Neural Networks with Applications to Tracking and Object Recognition. Submitted to the International Conference on Robotics and Automation 2017.

Object Recognition in Forward-Looking Sonar Images with Convolutional Neural Networks. To be submitted to IEEE/MTS Oceans'17 Aberdeen.

Research Area: Industrial Robotics

Design and Fabrication of an Affordable Hybrid Manipulator for Miniaturised Product Assembly

Supervisors: Dr Xianwen Kong, Dr Matthew W. Dunnigan
PhD Candidate: Mr Xavier Herpe
Research Associate: Dr Ross Walker

Objective
This project is to design a system that can pick, orientate and assemble parts between 1 and 10mm in size, with a target positioning accuracy of 5μm. The system is meant to be used for prototyping purposes such as assembling mobile phone cameras and sensors. It can fit on a desktop and the cost of hardware must be lower than £50k.

Approach
The system is designed using the concept of hybrid manipulation (Fig. 1). A 4-Degree-of Freedom (DOF) Gantry robot is used as the coarse positioning mechanism. A 2-DOF micro-motion stage is used as the fine positioning mechanism to compensate the positioning error of the Gantry robot. A 29 Mega-pixel vision system is used to locate the parts placed on a calibration grid which is fixed to the XY stage, and to measure the positioning error of the Gantry robot.

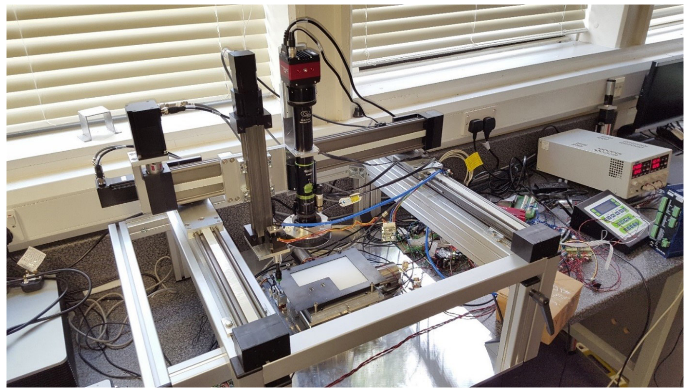


Figure 1. Hybrid micro-assembly system

The micro-motion stage (Fig. 2) that we have developed includes a compliant mechanism to decouple the motion along X- and Y- axes and improve its dynamic properties. Hybrid positioning is also integrated using dual-range sensor sets. The stage is driven by voice-coil actuators to obtain a smooth, frictionless and accurate motion. The coarse positioning is realised thanks to linear encoders measuring the input displacement of the stage over the full range but with an accuracy of only 5μm. Linear servomotors then bring capacitive sensors close to the moving platform of the stage and measure the output displacement over a short range but with an accuracy of 0.5μm.

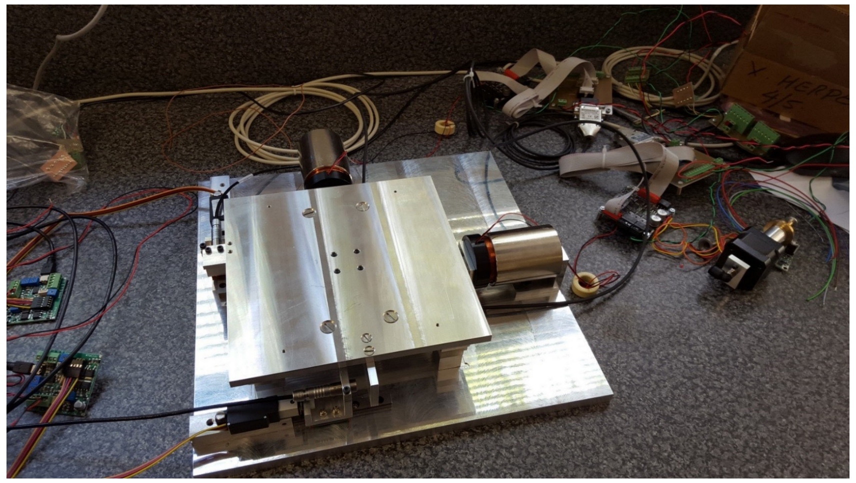


Figure 2 Micro-motion XY stage

Results
The Gantry system covers a workspace of 300mm x 400mm and has a positioning accuracy of ±1mm. The test results of the fabricated XY stage show a positioning accuracy of ±1μm for a workspace of 3mm x 3mm. The vision system integrated to the Gantry robot allows for a resolution of 2.8μm for a field of view of 12 mm x 18mm. The first system tests show promising performance for a hardware cost of around £40k.

Future Work
Future work includes developing a control system to make the assembly process semi-automatic. The accuracy of the assembly will be verified. This system will be integrated with a hybrid micro-machining centre and a handling system.

Impact
Conference proceedings

X. Herpe, R. Walker, X. Kong, and M. Dunnigan, "Analysis and characterisation of a kinematically decoupled compliant XY stage," in Proceeding of the 21st International Conference on Automation and Computing (ICAC), 2015, pp. 1-6.

X. Herpe, R. Walker, X. Kong, and M. Dunnigan, "Design, fabrication and testing of a hybrid micro-motion XY Stage driven by voice coil actuators," in Proceeding of the International Conference for Students on Applied Engineering (ICSAE), 2016.

Journal paper submitted

X. Herpe, R. Walker, X. Kong, and M. Dunnigan, "Modelling, design and characterisation of a kinematically decoupled micro-motion stage using a simplified analytical model," submitted to Mechanism and Machine Theory.

Acknowledgements
The authors would like to thank the Engineering and Physical Sciences Research Council (EPSRC), United Kingdom, for supporting this work under grant No. EP/K018345/1.

Research Area: Industrial robots

Control and Path Planning for Sweeping an Unknown Non-Flat Surface with a Robot

Supervisor: Dr Mustafa Suphi Erden
PhD Candidate: João Moura

Objective

The current cleaning process of the trains' exterior includes mechanized washers, which successfully wash the trains' side panels but fail to clean the train cab front nose and body-end panels between carriages. Due to the train cab front non-flat and complex shapes, specialized automatic washers tend to be fairly large, complex, and expensive. Moreover, such machines lack some flexibility and are, in general, unsuitable for different train cab front geometries.

Figure 1 Manual cleaning of a fuel powered train. Wembley depot, London. 9th of June of 2016

As a result, train-cleaning operations still comprise depot workers manually washing the front train panels, as shown Fig. 1. The laborious manual cleaning process motivates the study of the application of a flexible and inexpensive robotic and autonomous system (RAS) to this particular task. This study is conducted in relation to the "Cab Front Cleaning Robot" project, funded by the Railway Safety and Standards Board (RSSB), via the Rail Research UK Association (RRUKA), and within the consortium composed of Cranfield University (lead), Heriot-Watt University, Bombardier Transportation, Chiltern Railways, and Shadow Robot Company.

The goal of this project is to provide the control and path-planning framework that allows a robotic manipulator to sweep a 3D non-flat and smooth surface without using a surface model and external vision system. One of the underlying scientific and technical challenges to solve is how to make a cleaning tool, mounted at the tip of the robotic manipulator (the end-effector) follow and maintain contact with a complex 3 dimensional (3D) surface.

Approach

The proposed approach consists in using an Operational Space Formulation Implementation of an hybrid force/position control, using a trajectory obtained by projecting a two dimensional scan onto the three dimensional surface to be cleaned, with real-time path adaptation to local surface geometry nuances.
When assuming that the surface is unknown, one of the main questions is how can we plan a trajectory? Obviously we are unable to plan offline in advance of actual operation, because we do not have a prior model of the surface geometry; but even then we would like to cover a region with a specific type of movement, for instance, a spiral scan type of movement, emulating a cleaning operation.
The solution presented to this problem is to instead of specifying the trajectory directly in 3D, the cleaning tool follows a local direction that is obtained by projecting the path at the current locality on the surface. Overall, the movement is designed in a way that the resulting path on the surface would result in the projection of the 2D path onto the surface.

Results

Experiments using one of the 7 degrees of freedom (dof) Baxter arms validate the proposed strategy (Fig. 2). A force/torque sensor attached to the arm end-effector allows to measure the contact forces and torques, and to control the interaction force between the end-effector and the surface. A sponge attached to the force/torque sensor guarantees a compliant interaction between the arm and the surface.

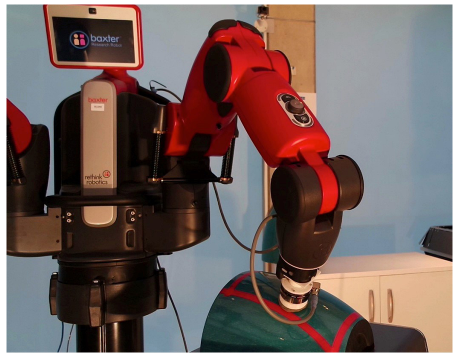


Figure 2 Baxter robot sweeping the test surface.

We developed and implemented an interaction-torque control scheme which guarantees in all times that the end-effector adapts to the surface variability in a way that it is always perpendicular to the surface tangent. After verifying that the end-effector was able to change the orientation according to the surface, we tested the trajectory generation through the aforementioned projection method. The results show that the robot is able to orient the end-effector according the surface inclination while keeping a constant contact force of 10 ± 5 N. The end-effector is also able to cover a region of the surface while performing a spiral motion.

Future Work

Future work includes: Estimating the friction forces in real time and feeding that information in the control to adapt the movement to different surface roughness; Learning the manipulator dynamics in real time while interacting with the surface; Estimating the surface geometry, in real time, and using such information in a feed forward loop, reducing the feedback control gains without compromising the position error.

Impact

Moura, J., Erden, M.S., Formulation of a control and path planning approach for a cab front cleaning robot. Through Life Engineering Services, 2016

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.

Robust Sensory Interfaces for Advanced Prosthetics
Touch Bionics, UK
This project aims to address the long standing challenge of obtaining alternate robust and reliable sensory interfaces and attempts a step-change in the dexterous control of advanced prosthetics and validates them through integration on cutting edge prosthetic limbs. The student explores appropriate methods for obtaining robust and reliable data through new sensory interfaces for prosthetics.

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.

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.

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.

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**

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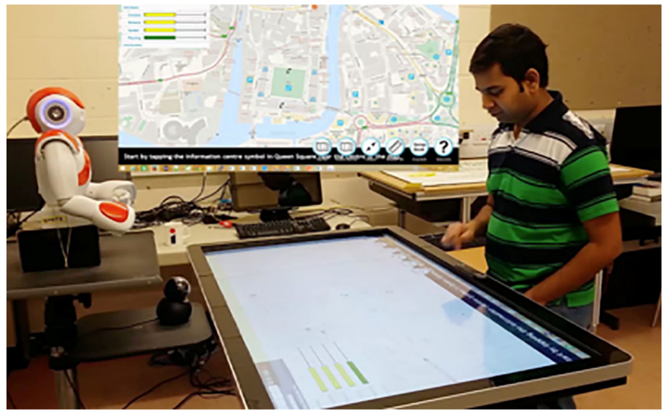


©Willow Garage

© Photo by John Buckley

Highlights 2015-16

“How Will Robotics Reshape Our Lives in the Next Two Decades”

This was the topic of a public debate co-hosted by the Centre and the British Science Association in Edinburgh in February 2016. This event was extremely popular, with tickets selling out on the first day. A panel of experts from the Centre and the University of Edinburgh talked about developments in AI and new challenges arising relating to privacy and data protection. The audience challenged the panel with topical concerns such as "Will robots take over our jobs in the near future?" and "Will the rise of robots lead to a decrease in human cognitive abilities?"

The debate attracted local media attention with an interview on BBC Radio Scotland on the morning of the debate, and articles in The Scotsman and the Edinburgh Evening News.

Robot RUKUS

As part of their initiative to raise the profile of the UK's engineering excellence amongst the New England robotics community, the British Consulate General Boston recently held a series of robotics-themed events to share 'What's Hot and So What' in start-ups, markets, and the robotics and AI sector.

Professor David Lane attended one of the panel sessions which considered the role of robotics in healthcare, autonomous systems, and defence applications. Fellow members on the "Autonomous Systems Panel" were Dr Michael Benjamin, Research Scientist at MIT; Mads Schmidt, Director of Unmanned Systems at QinetiQ North America; and Sampriti Bhattacharyya, Founder of Hydroswarm. Justin Manley, President of Just Innovation, moderated the panel.

Professor David Lane, Robot RUKUS

CBE Award for Centre Director

Congratulations to Professor David Lane who has been appointed Commander of the Order of the British Empire (CBE) for services to Engineering in the 2016 New Year's Honours list.

The Times Round Table on Disruptive Technologies

Professor David Lane was invited to London to participate in a round-table discussion on the implications of disruptive technologies, and how best to embrace them. The round table was organised by The Times in association with defence technology industry leader BAE Systems.

The backgrounds of those invited to the panel ranged from business strategists to academics, and this diversity made for a lively discussion. The debate touched on how we define disruptive technologies, and how this affects various stakeholders' positions on them.

Are they pioneering, fresh and exciting or simply unsettling, for consumers and the economy alike?

Are disruptive technologies the product of the fast-moving start-up culture and unrestricted innovation and or do they in fact play into the hands of venture capitalists and giants like Google?

Society of Petroleum Engineers webinar

Professors David Lane and Sethu Vijayakumar were invited by the Society of Petroleum Engineers DSATS (Drilling Systems Automation Technical Section) to present their thoughts on how robotics could address some of the challenges faced by the drilling industry.

Of particular interest to the audience was the adoption of automation in drilling, such as remote operation, underwater vehicles, human-machine interface, machine learning, visualization and analytics.

The presentation was made at one of the quarterly webinars that the Society hosts on topics of interest to its members. These webinars typically reach a global audience of 100 to 150 individuals through the real-time event and access to recordings.

To listen to the webinar, click here.

"Robotics and Autonomous Systems – Vision Challenges and Actions"

Professors David Lane and Sethu Vijayakumar participated at The Royal Society event: "Robotics and Autonomous Systems – Vision Challenges and Actions".

Professor David Lane discussed 'Creating Innovation from Invention: the UK RAS strategy and lessons from marine robotics'. Professor Sethu Vijayakumar delivered a lecture on the topic of 'Shared autonomy for interactive robotics: closing the loop'.

The full lectures are available on the Royal Society YouTube Channel

BBC micro:bit Live Lesson

This UK-wide BBC initiative aims to interest a new generation in digital technology. Professor Sethu Vijayakumar was invited along with PhD students, Alexander Enoch and Iris Kyranou, to talk about Valkyrie and to demonstrate ROBOTARIUM equipment such as the prosthetic hand.

Highlights 2015-16 (cont)

"Sharing autonomy (and responsibility): The robots are ready, are you?"

Professor Sethu Vijayakumar delivered the first lecture in the University of Edinburgh's Our Changing World series for 2015. This lecture series is designed to stimulate debate about the global challenges facing society and how academia might address these.
During his lecture, Professor Vijayakumar discussed current applications for state-of-the-art robots, as well as the trade-off between autonomy and control. He provided an overview of the technological and scientific advances in the Robotics sector before focussing on the more controversial issues and challenges associated with the use of robots in society.

Living with ethical robots

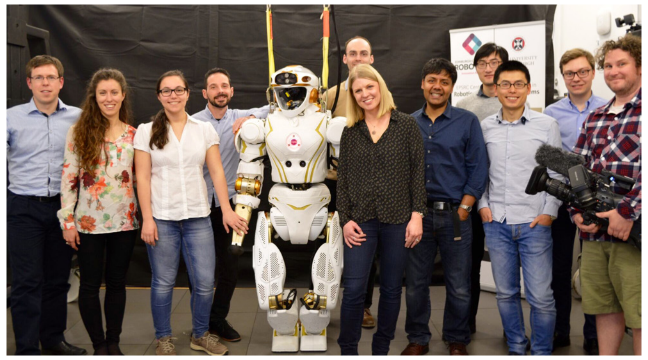
Dr Patricia A. Vargas was invited to write a blog for the Queen Elizabeth Prize for Engineering website on the topic of ethics and robotics.
The blog can be found here: http://qeprize.org/createthefuture/living-ethical-robots

First Annual Conference

In October 2015 the Centre welcomed over 100 delegates to its first annual conference. Keynote speakers included Professor Peter Corke from Queensland University of Technology, and Professor Darwin Caldwell from Istituto Italiano di Tecnologia. Professor Nick Weston from Renishaw highlighted the benefits to industry of sponsoring a PhD student, and the 2014 cohort of students presented their research and posters, and gave demonstrations of ROBOTARIUM equipment. The conference closed with an interactive session where industrial delegates and students were encouraged to collaborate to identify a market need for a RAS product and to work out how they could bring this to market with a Kickstarter budget of £20k.

NASA Valkyrie Project on the BBC

BBC journalists and crew covered our humanoid project on the BBC News at Six on May 4 and on BBC Breakfast the next day. The coverage was live streamed on the BBC Facebook page by reporter Victoria Gill where it was viewed by over 200,000 users, gathering over 2000 questions and comments. BBC News coverage here: https://goo.gl/7EcbeN



Conferences

Students from, or affiliated to, the Centre presented papers at the International Conference on Intelligent Robots and Systems (IROS) in Hamburg in autumn 2015.
They also attended and presented at the IEEE International Conference on Robotics and Automation in Stockholm in May.

Enterprising PhD student scoops prestigious RAEng Enterprise Fellowship

Sandy Enoch, a graduate of both Heriot-Watt and the University of Edinburgh, has scooped several awards for Marty, a robot that children can build and programme for themselves. Remotely controlled over Wi-Fi, Marty can walk, turn, dance and even kick a ball. Setting up and customising Marty can help users to learn about programming, electronics, mechanical design, 3D printing and robotics. The 20cm-high robot uses half the number of motors normally needed to make it move, which cuts down its production costs.

Catch the Next Wave

An exclusive conference designed for industry professionals and researchers with an interest in key disruptive technologies, the event in 2016 focussed on next generation robotics and automation. Professor David Lane was among leading global experts from the aerospace, medical, academic and marine industries who explored the latest technological advances from their fields and presented their vision for 2020.

Society of Petroleum Engineers (SPE) Intelligent Energy Conference and Exhibition

Professor David Lane participated along with other industry experts at the opening session which addressed the new economic landscape for the oil and gas sector. The panel considered the way back to profitability for the sector, what investors are looking for and the role that Intelligent Energy might play in future investment decisions.

Centre Visits to Japan and China

Centre Directors were invited to join a high-profile UKTI delegation to promote UK robotics in China and Japan where they made presentations at the respective embassies and attended exhibitions amongst them iREX. Productive meetings were held with the Shenyang Institute of Automation, Northeastern University in Beijing, Kobe Shipyard, Kawasaki Heavy Industries, Honda and local professional bodies.

Cabinet Office presentation and discussion

In May, Professor David Lane accepted an invitation to present at one of a series of 'horizon scanning' meetings of the Westminster Cabinet Office, chaired by Cabinet Secretary with the Government's Chief Scientific Adviser and Heads of Government Departments. A broad discussion ensued as Govt departments shared best practice and opportunities for the use of robotics and autonomous systems, from self driving cars through assistive companion robots and use in hazardous environments to drone deliveries.

Public Outreach

Academics and students continue to actively seek out opportunities to participate in outreach events within the local community.
Activities in the last year include attendance at Scotsoft, the premier Scottish digital technology event; Living Machines, the 5th International Conference on Biomimetic and Biohybrid Systems; the Edinburgh International Science Festival and a series of events hosted by the Scottish Parliament.

Edinburgh Centre for Robotics students enjoy success at the Science Festival

Students ran a Robot Lab at the Edinburgh International Science Festival in spring 2016 to showcase the research being carried out by students at the Centre. This event was visited by around 4000 children and parents over the course of 5 days and was well received by all age groups. Students also gave a series of talks under the heading "Technologies of the Future, Today".
After visiting the Science Festival, **Dara Ó Briain, presenter and host of Robot Wars**, said in an email to Professor Sethu Vijayakumar, Edinburgh Centre for Robotics Director:
"The Science Festival exhibits have been excellent so far, and your students were doing a great job with the robots."

Our students also benefited greatly from participation in this event.

Eli, PhD student, 2015 cohort commented:
"Working at the science festival was a great experience. Being able to meet so many kids who are excited about science - and especially robots was really rewarding. I also got to meet many parents who were just as excited as their kids."

James, PhD student, 2014 cohort, who made it all happen, explains why he decided to get so heavily involved in this year's festival:
"I've been interested in public engagement with STEM for a long time now and I volunteered to help run a workshop at the 2015 Edinburgh International Science Festival. This year I decided I would push myself to do more and so I got in touch with the Science Festival about organising multiple events on behalf of the Edinburgh Centre for Robotics. It took a lot of work, but getting to see thousands of people engaging with, and enthusiastic about, our research area made it all worthwhile!"

TurtleBots make an appearance at the Living Machines conference

Three students from the Centre attended the Living Machines conference in July 2016 and demonstrated TurtleBot robots. These low-cost, personal robot kits which can be used to map their environment were one of the star attractions at the conference, proving a big hit with both young and old alike.

Teun, PhD student, 2014 cohort commented:
"It was a very interesting experience to be at the other side of the table for once. Having had very little time before the event to explore the capabilities of the robot we were demonstrating, it was challenging to answer questions from the audience. ROS (the software that runs on the robot) is easy to configure but if I had a bit more time I would have installed a newer version of ROS to make the robot more stable. The event was well organized and allowed us to talk to other participants as well to see what they were doing. All in all it was great fun to interact with people of all ages."

Boris, PhD student, 2015 cohort stated:
"Children as well as adults loved making robots follow them around the exhibition area. Spectators were bewildered by the outstanding performance and accuracy of the robots and how natural their movements were."

Nao Robot visits St George's School

Professor Sethu Vijayakumar recently took one of the Nao robots on a visit to St George's School in Edinburgh where lots of fun was had emulating the robot's moves.

Professor Vijayakumar was awarded the 2015 Tam Dayell Prize for Excellence in Engaging the Public with Science for his various outreach activities.

Scotland's Science - Past, Present and Future

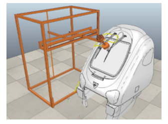
The Edinburgh Centre for Robotics featured strongly in the Heriot-Watt University showcase of Laser-based Manufacturing, Marine Science and Robotics at the Scottish Parliament reception celebrating 'Scotland's Science - Past, Present and Future'. The event was held in December 2015 at Our Dynamic Earth and was hosted by Dr Alasdair Allan MSP, Minister for Science, Learning and Scotland's Languages.
Feedback after the event was extremely positive, with the Heriot-Watt University exhibition having made a significant impact with the inclusion of the robotic displays organised by the Centre.

Awards

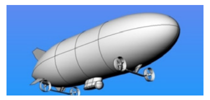
HITACHI

Warehousing Automation
This project, funded by Hitachi Central Research Labs (CRL), Tokyo, looks at the challenging problem of adapting motion plans of a mobile manipulator to deal with changing environments and configurations. It uses cutting edge research developed in the field of topological representations and dynamic replanning at ECR. The application domains broadly lie in the area of warehouse automation in shared human-robot workspaces and deals with challenges arising out of stochastic motor execution, noise in odometry and sensing as well as bi-manual operations for cumbersome grasping tasks.

EU:MANgO: federated world Model using an underwater Acoustic NetwOrk
MANgO is developing a form of underwater Dropbox for distributed marine robots using acoustic modems of opportunity in an underwater internet of things. This is challenging in a communication medium with limited bandwidth and range, long latencies and significant numbers of dropped packets. Linking to the autonomous host and its mission, the research is to establish the most important items to transfer first and to route appropriately, including re-transmit with non receipt. Trials with partners from University La Sapienza in Rome and Tallinn University of Technology will demonstrate this using ROBOTARIUM unmanned marine platforms and sensors in sheltered open water.



Rail Safety & Standards Board: Cab Front Cleaning Robot
In collaboration with Cranfield University, Bombardier Transportation, Chiltern Railways and Shadow Robot Company, this proof-of-concept project will develop a prototype robot for train cab front cleaning which is currently a manual process. The development of a robotic cab cleaner will address current health and safety concerns as well as reducing operating costs.



FAPESP São Paulo Research Foundation: Smart Airships Swarm and Robotic Ground Electrical Vehicles for Environmental Monitoring and Surveillance (SAS-ROGE)
This project will investigate the design, calibration and testing of an integrated simulator of a multi-robot-system comprised of a "smart airships" swarm and robotic ground electrical vehicles for environmental monitoring and surveillance. Such multi-robot-system can be used in the future to address a number of major challenges that affect millions of people both in Brazil, UK and worldwide including disasters, search and rescue, monitoring of remote access areas, animal herding and agriculture applications.

MaDrIgAL

EPSRC: Multidimensional Interaction management and adaptive learning (MaDrIgAL)
The proposed project aims to develop a radically new approach to building interactive spoken language interfaces by exploiting the multi-dimensional nature of dialogue. This principled account of the multiple parallel aspects of communication, such as feedback and social conventions, will not only allow us to build systems that support more natural and effective interactions with users, but also enables cost-effective development of such interfaces for a variety of domains by learning transferable skills. MaDrIgAL will bring together expertise in statistical approaches to state-of-the-art spoken dialogue systems and natural language generation as well as linguistically motivated theories of multi-dimensional dialogue modelling supplemented with expertise from an industrial viewpoint.

[dstl]

DSTL ASUR: REport GeneratIon from MEtadata (REGIME)
The two main barriers to wide spread adoption of autonomous unmanned systems are the lack of trust in the systems and information overload of operators and personnel. REGIME investigates natural language report generation techniques to address these issues, optimising situation awareness during and post mission and ensuring that the rationale behind autonomous systems' decisions is completely transparent- this is particularly important for underwater vehicles where bandwidth is limited.

THE ROYAL SOCIETY

Planning movements in constrained environments
The Royal Society announced 8 new fellowships aimed at strengthening links between academia and industry. The fellowships are awarded to academic scientists who want to work on a collaborative project with industry and for scientists in industry who want to work on a collaborative project with an academic organisation.
The main purpose of this project is to apply a representation based on graph Laplacian for encoding the spatial relationships between different body parts for motion retargeting (applying the motion capture data to those characters of different sizes, mass, etc.). The project will target various applications such as computer games, movies, and robot control in theme parks.

Ways to engage with the Centre

Sponsor PhD Research

In return for sponsoring a relevant PhD research project at the Centre, a company can gain early access to the results, the potential to exclusively licence foreground IP and the right to host the student at their site for 3 months of the project.

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

Collaborative Research Projects

The central theme running throughout our research is Interaction:

Environment; Multi-robot; People; Self; Enablers

We welcome the opportunity to discuss potential collaborative projects with research institutions in the UK, EU and USA.

Details of our academic staff and their research interests can be found on our website:
www.edinburgh-robotics.org/people

Robotarium

A £7.2M investment in enabling equipment, the ROBOTARIUM comprises four integrated and interconnected components. These create a unique integrated capability for exploring collaborative interaction between remote teams of humans, robots and their environments at all levels.

ROBOTARIUM is a national UK facility which is generally available to researchers for proof of concept experiments. We also welcome enquiries from companies engaged in the development of new products and services.

For further information about the ROBOTARIUM facilities, please refer to our website www.edinburgh-robotics.org/robotarium or e-mail enquiries@edinburgh-robotics.org

This publication is available online at:

www.edinburgh-robotics.org/reports

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

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